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FASTS: a radar simulation model for the development and analysis of aircraft anti-ship tactics.

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NAVAL POSTGRADUATE SCHOOL
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THESIS

FASTS: A RADAR SIMULATION MODEL
FOR THE DEVELOPMENT AND ANALYSIS
OF AIRCRAFT ANTI-SHIP TACTICS

by

Frank O. Barrett III

September 1985

Thesis Advisor: R. N. Forrest

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This thesis describes an interactive computer program that was developed by the author. The program which is called FASTS simulates a many-on-many war-at-sea scenario involving ship based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of environmental conditions on radar detection.

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FASTS: A Radar Simulation Model for the Development and Analysis of Aircraft Anti-Ship Tactics

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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September 1985

ABSTRACT

This thesis describes an interactive computer program that was developed by the author. The program which is called FASTS simulates a many-on-many war-at-sea scenario involving ship based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of environmental conditions on radar detection.

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I. INTRODUCTION

Recent advances in ship anti-air defensive systems have brought about significant changes to the War-at-Sea (WAS) battle environment. Improved surface-to-air missiles are able to kill incoming raid aircraft at longer ranges and at lower altitudes. In addition, close-in weapon systems designed to rapidly engage and destroy penetrating raids and missiles are widely deployed and have demonstrated a measure of success, and supporting radar systems have grown in both power and countermeasures sophistication.

Efforts to improve aircraft strike capabilities while reducing attrition have been directed toward reducing the time the attacker is exposed to the hostile environment. These efforts have led to the incorporation of low altitude flight profiles and standoff jamming into strike tactics for the purpose of delaying or preventing initial detection and degrading the enemy's fire control solution.

The development and evaluation of effective coordinated strike tactics that incorporate low altitude flight profiles and standoff jamming for the multi-threat radar scenario has proven a challenging problem for planners. The constantly varying aircraft, jammer, and radar geometrical relationships and the complex effects of the atmosphere on radar propagation

are not easily analyzed and understandably often have given way to broad assumptions of capability which have led to standard, invariant and often sub-optimum tactics.

A. RECENT DEVELOPMENTS

The introduction of the Integrated Refractive Effects Prediction System (IREPS) into the fleet provided a major tool for the tactical exploitation of the effects of atmospheric conditions on radar propagation. By providing a shipboard capability to predict radar coverage and propagation anomolies; IREPS highlights altitudes of radar energy ducting and demonstrates that in many cases the use of low altitude attack profiles over water actually increased aircraft detection ranges. Similarly, the ducting of radar jamming energy can either magnify or reduce its effectiveness.

Additionally the vastly increased capability in computing power and speed brought about by the new generation of desk-top computers is now at the disposal of the tactician. Complex simulation programs, which until now required a near main-frame capacity, can be conveniently run on small computers such as the HP-9000 series which are presently maintained in the fleet.

B. THESIS RESEARCH OBJECTIVE

The objective of the research described in this thesis was to develop a computer program that through simulation would provide a capability to predict the effectiveness of

shipboard radar performance against airborne targets in the presence of jamming and anomalous propagation effects. A program was developed which is called FASTS; its development and characteristics are described in what follows.

II. BACKGROUND

The basic issue to be considered in assessing radar detection of a target is the following:

> Is the reflected radar energy from the target detectable when superimposed with jamming signals and receiver noise?

The following models for radar and jammer signal propagation, receiver noise, and target detectability were used to determine the probability of defection for airborne targets in FASTS.

A. THE RADAR MODEL

Through the years, various efforts have resulted in the development of descriptive models that predict the performance of radar (and radar jamming) systems. These models are not exact but they do permit meaningful and consistent analysis and as such are most useful.

Until the recent past, general practice has been to assume that the radar and target were located in free space since the non-free space signal propagation effects are considerably more complex and difficult to calculate. The use of computers to perform these calculations has made it possible to quickly evaluate non-free space propagation factors and improve the accuracy of the radar model.

The following is a development of the radar transmission equation. The forms are simplified to allow one to easily

identify the quantities which must be evaluated when considering environmental factors. This derivation follows from A Guide to Basic Pulse-Radar Maximum-Range Calculation by Blake [Ref. 1].

It is convenient to follow the path of the energy from its transmitter to the target and back to the radar receiver. If one can assume that a transmitting antenna radiates isotropically (uniformly in all directions), then the power density (watts per unit area) at any point at distance R is:

$$\text{Power Density at R} = \frac{P_t}{4\pi R^2} \tag{1}$$

where P_t is the total power radiated, and $4\pi R^2$ is the area of a sphere of radius R.

However since radar antennas are directional, the power density at distance R is:

$$\text{Power Density at R} = \frac{P_t \; G_t}{4\pi R^2} \tag{2}$$

where G_t is the on-axis gain of the transmitting antenna.

If a target at range R intercepts an amount of power contained in an area σ square meters and reradiates it isotropically, the power density returned to the antenna will be:

$$\text{Power Density at Receiving Antenna} = \frac{P_t \; G_t}{4\pi R^2} \sigma \frac{1}{4\pi R^2} \tag{3}$$

The receiving capture area of an antenna is, by definition, the ratio of power delivered to the radar receiver (P_r) to the field power density:

$$A_c = \frac{P_r}{\text{Power Density}} \tag{4}$$

For a receiving antenna gain of G_r, the capture area is:

$$A_c = \frac{G_r \lambda^2}{4\pi} \tag{5}$$

Combining equations (3), (4) and (5) yields:

$$P_r = \frac{P_t G_t}{4\pi R^2} \sigma \frac{}{4\pi R^2} \quad \frac{G_r \lambda^2}{4\pi} \tag{6}$$

For radars using the same antenna for transmitting and receiving, G_t and G_r can be assumed to be equal, and thus, with rearranging the equation for radar transmission in free space becomes:

$$P_r = \frac{P_t G^2}{(4\pi)^2 R^4} \sigma \frac{\lambda^2}{4\pi} \tag{7}$$

When free space propagation conditions are not met, this equation will not give a correct result. A solution is provided by inserting into the equation a pattern-propagation factor F which accounts for wave propagation effects due to non-free space conditions and effects of the antenna pattern. When the same antenna is used for transmitting and receiving, the factors are identical and are combined. The equation can now be presented in the following form:

$$P_r = P_t G^2 \sigma \frac{\lambda^2}{4\pi} \left[\frac{F}{4\pi R^2} \right]^2 \tag{8}$$

where the bracketed quantity is composed of factors which are dependant on target and radar relative positions and represents the one-way transmission loss for the radar signal.

B. THE RADAR JAMMING MODEL

Noise jammers produce a signal which adds to the thermal noise already present in the radar receiver. The jamming noise power received is derived in much the same way as for the radar equation and is given by:

$$N = \frac{P_j \; B_r \quad G_j \; G_r \quad \lambda^2}{B_j \; L_p \quad 4\pi} \left[\frac{F}{4\pi \; R^2} \right] \qquad B_j > B_r \tag{9}$$

where P_j = Jammer Power

B_j = Jammer Bandwidth

B_r = Radar Receiver Noise Bandwidth

G_j = Jammer Antenna Gain

G_r = Radar Antenna Gain

F = Pattern Propagation Factor

R = Jammer to Radar Range

L_p = Polarization Loss Factor

The polarization loss factor included in Equation (9) is required when the polarization of the jamming system does not match that of the radar system. The loss factor would be infinite if the jamming antenna and the radar antenna could be perfectly cross polarized. In general the jammers will not have the same polarization as the radars. In order to accommodate a variety of polarizations, jammers are often either forty five degrees slant polarized or are circularly polarized resulting in an L_p of two. [Ref. 2:p. 3a-1]

C. RADAR ENVIRONMENTAL PROPAGATION LOSSES

The propagation of radar waves is affected by interaction with both the earth's surface and the atmosphere. Under certain conditions, environmental factors can substantially alter propagation factors and therefore be critical. It is necessary to distinguish between two different regions shown in Figure 1 when discussing radar propagation. One is the optical region which extends within the line of sight of the radar. The other is the diffraction region which lies beyond the horizon.

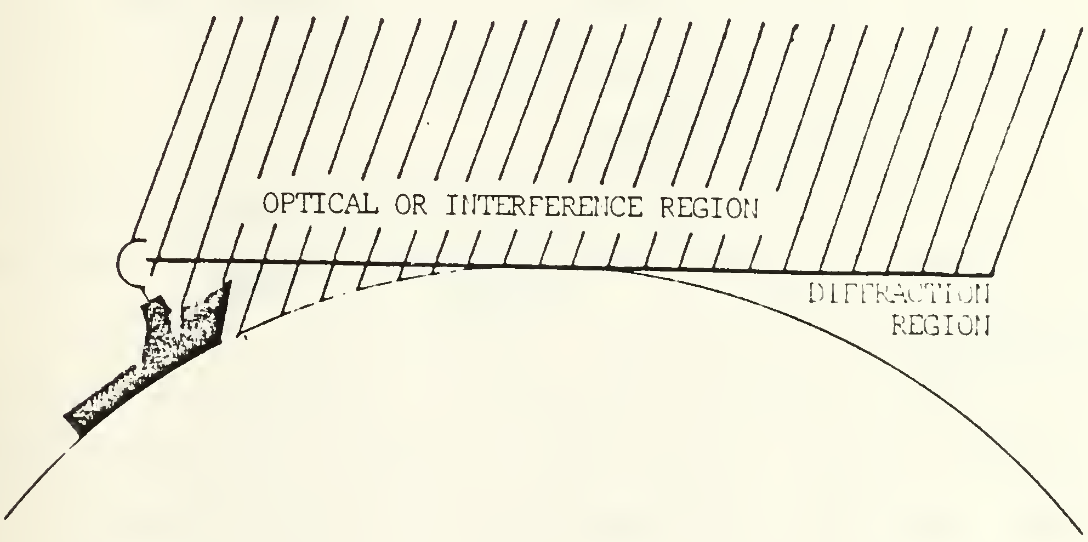

Figure 1. The Optical and Diffraction Regions

1. The Optical Region

Within the optical region, radar energy travels with spherical spreading generally in accord with the free space equation. When targets or radar transmitters are located near a large smooth surface like the ocean a portion of the energy is reflected off that surface. For shallow incidence angles and with smooth seas, nearly 99 percent of the energy is reflected with 180 degrees of phase change. With surface roughness, due to wind, the magnitude of the reflected energy can decrease to about 15 percent of the incident energy (still with 180 degrees of phase difference). As the transmitter to target geometry changes, the relative lengths of the direct and reflected paths also change. The received signal at the target is the vector sum of both the direct and reflected energy which causes received power to vary from 6 dB above (signals in phase) to 20 dB below (signal 180 degrees out of phase) the free space values.

2. Diffraction Effect

Radar energy in the diffraction region is usually due to diffraction by the curvature of the earth or refraction by the earth's atmosphere. The relatively weak field resulting from diffraction, which is predicted by electromagnetic theory, is generally too small to be effective for radar detection. At ranges beyond the radar horizon, propagation is dominated by a mechanism called tropospheric

scatter or troposcatter. This process of wave scattering due to certain heterogeneities causes path loss values that are so high it is impossible for any known radar to successfully detect targets. [Ref. 3]

3. Refraction and Anomolous Propagation

Although radar waves travel in straight lines in free space, waves in the atmosphere are bent or refracted due to the variation of the velocity of propagation with altitude. The effect is to extend the distance of the radar horizon beyond that for straight-line propagation. See Figure 2. The classical method of accounting for refraction is computations is by replacing the actual earth of radius a with an equivalent earth of radius ka and by replacing the

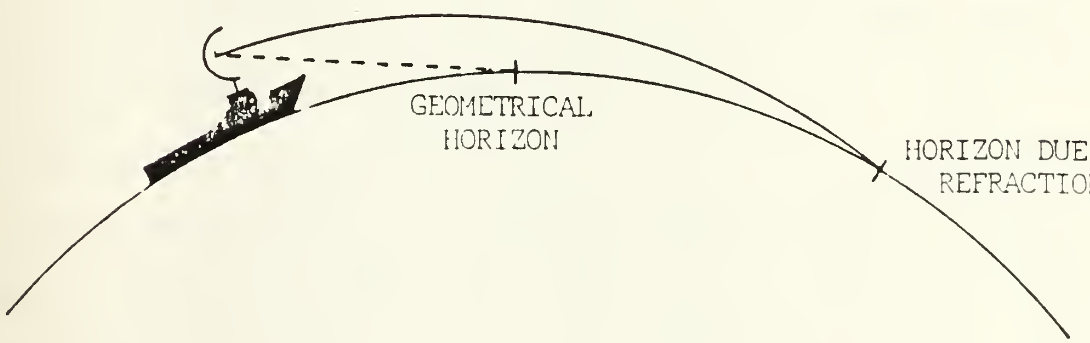

Figure 2. Horizon Extension Due to Refraction

actual atmosphere by a homogeneous atmosphere in which radar waves propagate in straight lines rather than curved lines. [Ref. 4:p. 449] For standard atmospheric conditions the value of k used is 4/3. The distance to the radar horizon can be shown to be approximately:

$$d = \sqrt{2\ k\ a\ h} \qquad \text{or}$$

$$d(\text{nautical miles}) = 1.064\ \sqrt{k\ h(\text{ft})} \tag{10}$$

where h is the antenna height.

The most dramatic effects of refraction occur when the gradient of the index of refraction is sufficient to allow initially horizontal rays to be bent to very nearly follow the curvature of the earth. This condition is known as superrefraction, and such rays are said to be trapped. Rays normally can be trapped only if they originate within a layer of such conditions called a duct. Surface ducts extend upward from the surface to a height of a few hundred feet and on rare occasions up to one thousand feet. In the duct rays are bent down toward the ocean until a reflection occurs. The upward reflected ray is then gradually bent downward again until it again reflects from the surface. See Figure 3. A duct can be compared to a leaky waveguide; some fraction of the energy traveling within does escape. Generally energy coupled within a duct has an elevation angle to the duct of less than one degree and probably less than one-half degree [Ref. 5:p. 226]. These anomolous propagation conditions occur for k values greater than two.

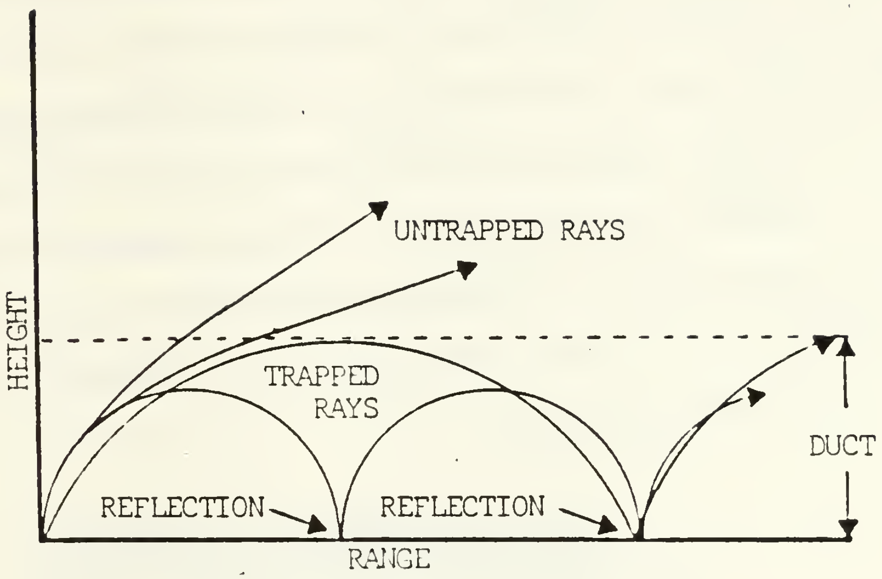

Figure 3. Radar Energy Propagation in Surface-based Duct

The ducting conditions restrict the spherical spreading of energy resulting in both extended ranges for energy trapped within the duct and reduced energy, or radar holes, outside the duct. Because the wave is trapped within the duct, vertical spreading of the wavefront is prevented. Since the wave is spreading in only one dimension rather than two, the average rate of power density decrease is reduced to 1/R (vice $1/R^2$ for the free space model). [Ref. 5:p. 227] Therefore a target located in or near a surface duct may be detected at a range beyond the normal free space detection range as well as below the radar horizon.

Figure 4 illustrates a typical one-way signal loss versus range profile demonstrating interference effects in the optical region and increased losses in the diffraction and troposcatter regions.

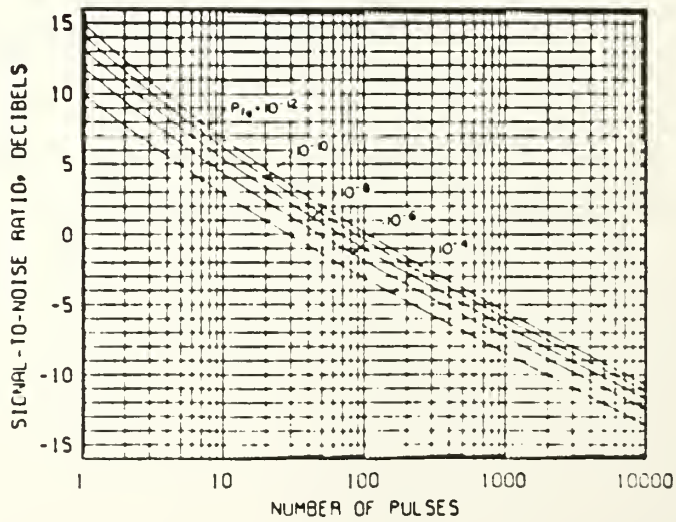

Figure 4. Required Signal-to-Noise Ratio for Detection with Noncoherent Integration of Pulses; Square-Law Detector, Swerling Case 3 Fluctuation, P_d=0.50 [Ref. 7]

The radar loss module of the IREPS computer package can be used to predict duct propagation for specified refractive index profiles. (For more details, consult Reference 3.)

D. DETECTION MODEL

When a radar target return signal is present within a noise or jamming background, the probablity of detection is a function of its visibility factor which is the degree to which the received signal-to-noise (S/N) ratio exceeds a radar-specific detection threshold. The relationship between the detection probability and this excess signal-to-noise quantity is a function of both an associated probability of false alarm (Pfa)--the probability that noise alone will cause the threshold to be exceeded--and the assumed distribution functions for the level of the signal. For the latter the Swerling Case III model for scan-to-scan fluctuations is considered most appropriate for targets such as jet aircraft and missiles [Ref. 6:p. 276].

Detection probability on a scan is enhanced by the integration or combining of signals by either radar display persistance or other electronic means. The benefit of integration is primarily due to the reduction or smoothing of noise variation [Ref. 5:p. 42]. The effect is to lower the required visibility for target detection. See Figure 5.

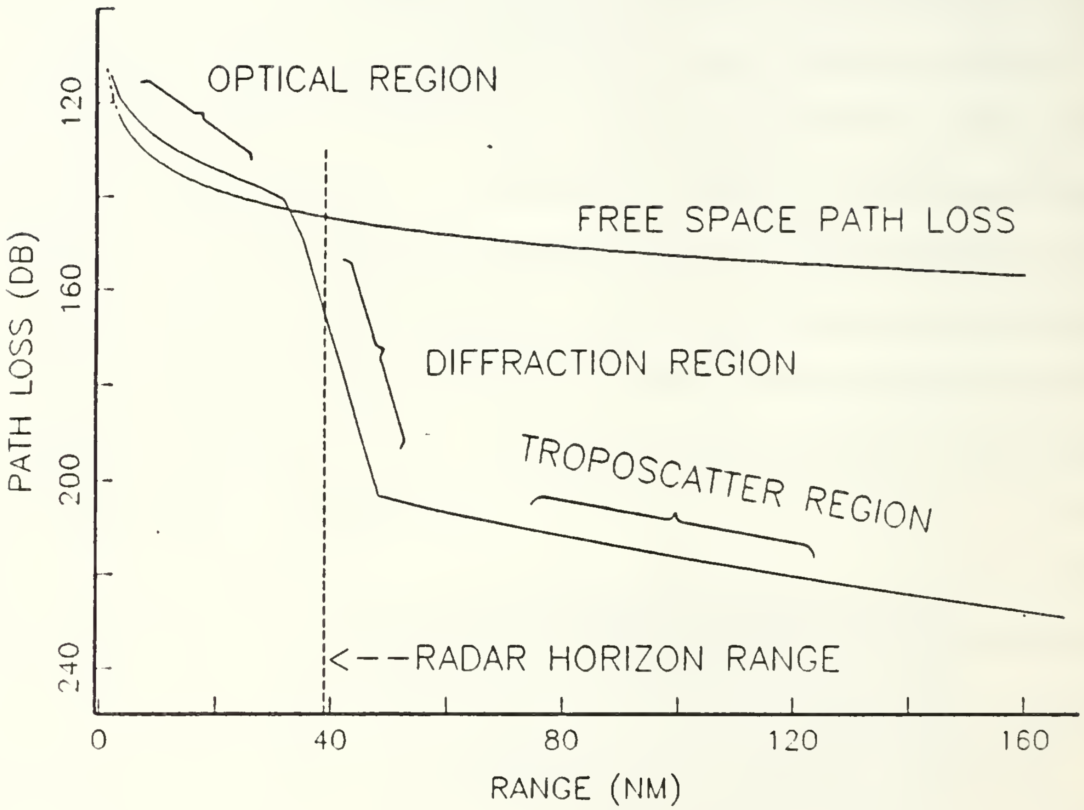

Figure 5. Path Loss for a 5000 MHz Transmitter at 90 feet and a Receiver at 500 feet for a Standard Atmosphere

A relationship between detection probability and <u>excess</u> signal-to-noise ratio was developed by the Johns Hopkins University Applied Physics Laboratory [Ref 7.]. The relationship is:

$$P_d = .5 \quad 1 + \sin[(\text{excess } (S/J))(\pi/18)] \tag{11}$$

for Pfa = 10 -6

N = 10

and $-9 <= S/J < = 9$

to data obtained from Reference 7. (See Figure 6.)

E. OPERATOR FACTOR

Experts have postulated that when an operator becomes tired, bored or partially distracted, his efficiency is reduced and the probability of operator detection of a target is similarly diminished. This can be expressed in terms of an operator factor, P_o, which is defined as the probability that an operator will see a target signal that is detectable by an alert and perfect operator. It follows, therefore, that P, the probability that a scanned target is seen by the operator, can be expressed in equation form as:

$$P = P_o \; P_d \tag{12}$$

where P_o is the operator factor, and P_d is the previously derived probability of detection.

The nature of an operator factor is controversial. The operator factor often has been used to explain <u>all</u> differences between actual and theoretical performance. Although

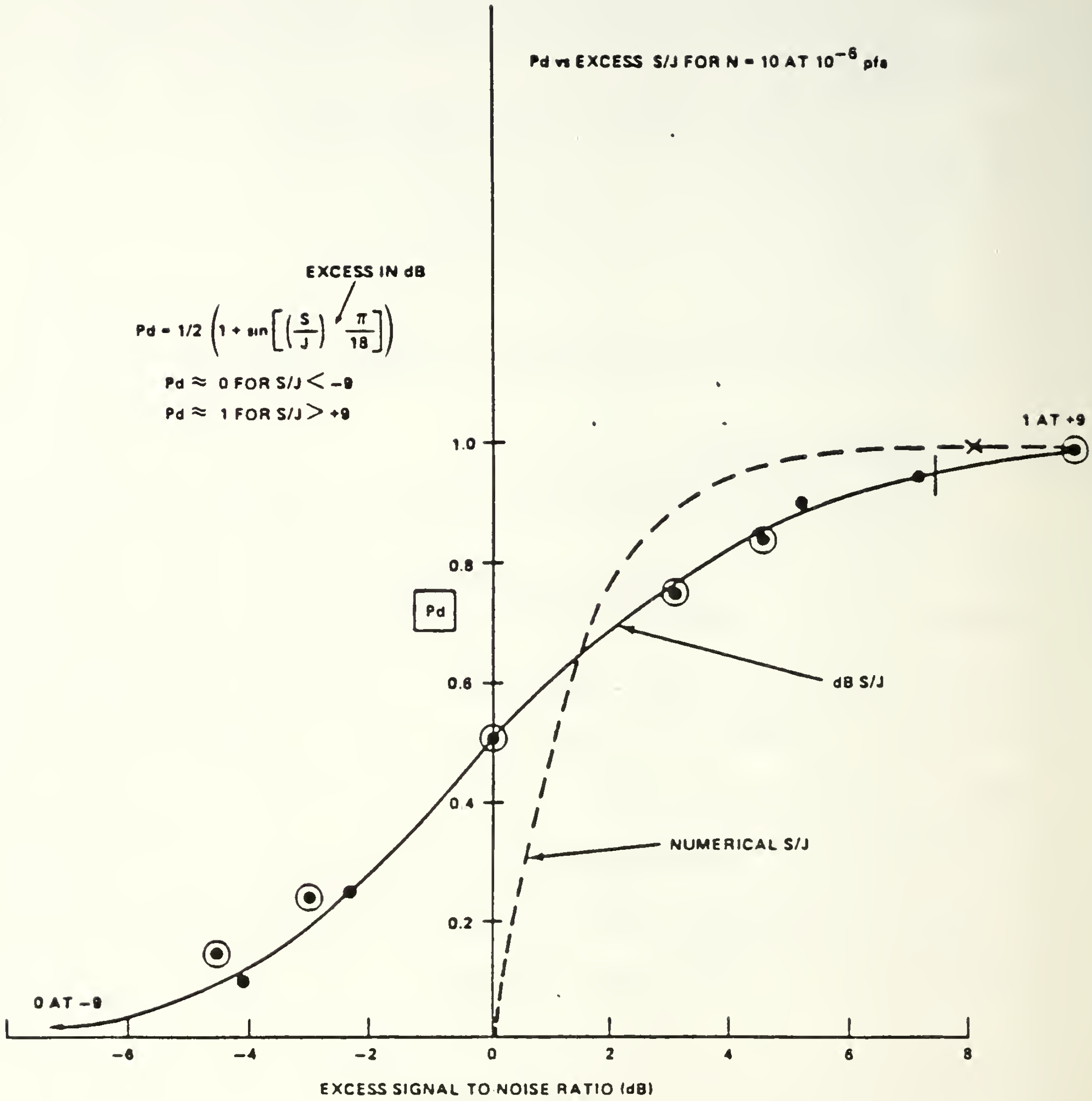

Figure 6. Probability of Detection versus Excess Signal-to-Noise Ratio for Probability of False Alarm of 10^{-6} and an Integration Factor of 10

originally proposed to be constant for a given operator or operator and experiment, research has shown operator performance to vary with signal strength, display brightness, radial and azimuthal position on the scope and numerous other factors [Ref. 8].

Scolnik and others lend support to a simple model of operator efficiency under good conditions. Scolnik's model uses the following relationship to determine the probability an operator will detect a target:

$$P = 0.7\ (P_d)^2 \tag{13}$$

This can be interpreted as follows: An operator must first see a target signal on some scan and then see the target signal on the successive scan for detection to occur [Ref. 4:p. 253]. For this model, the operator factor for the first scan could be considered to be equal to 0.7, and that for the second scan, to be 1.

III. THE PROBLEM SOLUTION

A. PROGRAM OVERVIEW

The Fleet Anti-Ship Tactics Simulator (FASTS) is written using the HP 9000 Series 500 BASIC Language System for use on the HP 9000 Series Model 520 Computer. The program source code is contained in Appendix A. It employs the general structure and computational methods used in the Modified Jamming Aircraft and Radar Simulation (JARSM), a PL/I LANGUAGE program supported by the IBM 3033 system [Refs. 7 and 9]. Several modifications have been implemented to JARSM aircraft maneuvering and radar processing routines, the largest of which incorporates mechanisms for calculating radar path signal losses using modules from the IREPS program developed by NOSC.

FASTS simulates a many-on-many war-at-sea scenario involving ship-based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of certain environmental conditions on radar detection.

FASTS is implemented on an unbounded x-y coordinate grid and is controlled by a main routine clock which steps from time zero to a finish time provided by the user. A separate

parameter data file is appended automatically to the program for each scenario. Scenario data includes:

1. Radar parameters for up to 15 radar types
2. Radar locations for up to 15 radar systems
3. Jammer parameters for up to 15 jammer types
4. Aircraft radar cross section data for up to 15 aircraft
5. Aircraft location and flight profile data
6. Scenario time increment
7. Environmental data

Specific input parameters and format are defined in Appendix B.

There are four types of output available from FASTS: a time history of aircraft position, velocity, and probability of detection; a geographic plot of aircraft tracks and visibility; a plot of aircraft detectability versus time; and a simulation-based table of expected first-detection ranges for each aircraft and radar combination.

The program is written in structured format. Program flow is controlled via the Main Routine illustrated in Figure 7.

B. INITIALIZATION SUBROUTINE (INIT)

The most critical part of the FASTS program from the user's point of view is the data input. Subroutine INIT reads scenario parameters from the input data file (Appendix B refers)

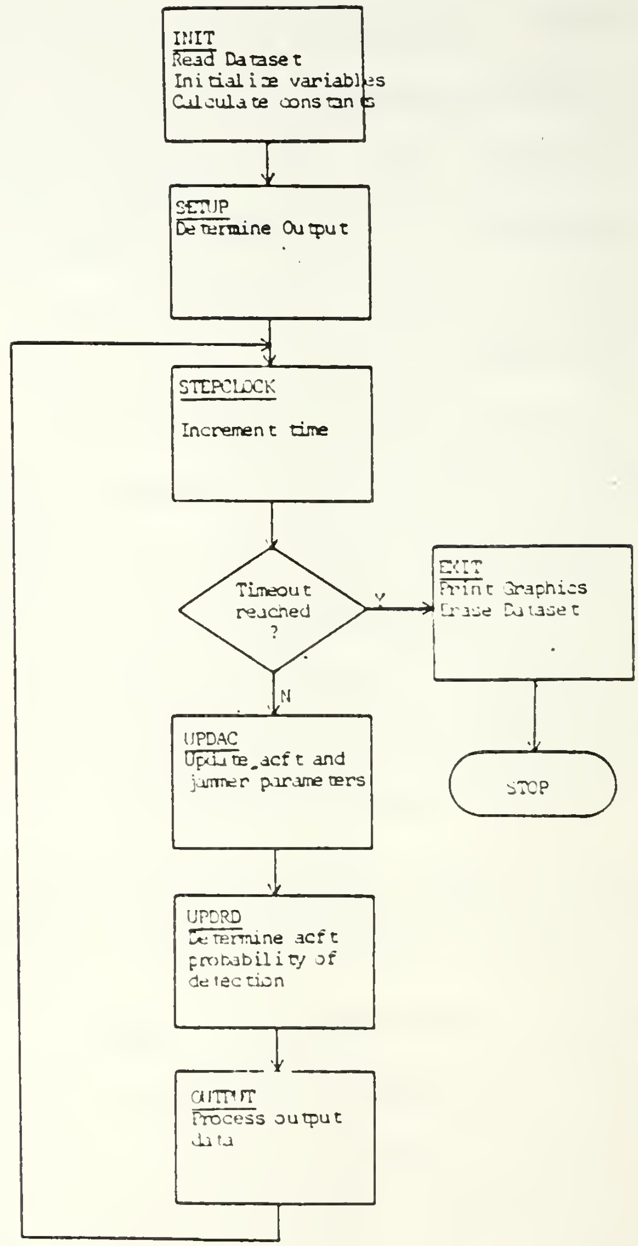

Figure 7. FASTS Main Routine

and processes them for program use. The following specific data elements are required:

1. Environmental parameters
   a. Effective earth radius factor
   b. Duct height (ft)
   c. Wind velocity (knots)
2. Time parameters
   a. Simulation time increment (sec)
   b. Finish time (sec)
3. Radar type parameters
   a. Effective radiated power (dB)
   b. Frequency (MHz)
   c. Antenna gain (dB)
   d. Receiver figure of noise (dB)
   e. Receiver noise bandwidth (MHz)
   f. Receiver loss (dB)
   g. Scan period (sec)
   h. Antenna type
   i. Azimuth bandwidth (degrees)
   j. Elevation bandwidth (degrees)
   k. Azimuth sidelobe gain (dB)
   l. Antenna pattern
   m. Antenna polarization
4. Radar site parameters
   a. Type of radar
   b. Location coordinates (x,y in nm)
   c. Antenna altitude (ft)

5. Jammer type parameters

    a. Effective radiated power (watts)

    b. Bandwidth (MHz)

    c. Frequency (MHz)

6. Aircraft type parameters--Radar aspect angle and associated radar cross section

7. Aircraft parameters

    a. Initial location, altitude, heading and speed

    b. Aircraft flight profile containing changes to each aircraft's position/velocity data and jammer status

The program time increment, D_t, is set to the minimum radar scanning interval (over all scan rates) if it is found to be less than the time increment read from the data file. Lastly frequently used constants for radar equation and jammer power equation calculations are computed for each radar and radar-jammer combination.

C. AIRCRAFT MODULE (UPDAC)

Subroutine UPDAC in FASTS controls the flight path for each aircraft in the scenario. The position, altitude and airspeed for each aircraft are updated at each clock increment. The aircraft is flown or controlled through the use of tactical commands issued from the scenario data file.

Seven different tactical commands are available:

1. JAM ON--Initiate jamming with a designated type of jammer

2. JAM OFF--Cease jamming with a designated type of jammer

3. CLIMB--Climb or dive to a specific altitude at a specific rate

4. TURN--Fly to a specific heading at a specific rate

5. HOME--Turn aircraft at each time iteration toward a specific radar site

6. FOLLOW--Maneuver with a specific aircraft

These instructions are stored and executed sequentially according to their initiation times. Due to the discrete time intervals of the simulation, the aircraft flight path is constant between update points. Thus, its flight path consists of a sequence of straight line segments. If the velocity of an aircraft is reduced to zero knots, it is removed from the simulation. This feature can be used to terminate aircraft tracking before the end of the simulation. Aircraft velocity is automatically set to zero whenever its velocity decreases to less than ten knots or its time-to-close the target of a HOME command is less than the simulation time increment.

The FOLLOW command was implemented as a convenience to enable aircraft to proceed in the company of another without having to repeat all maneuvering commands of the flight leader. This command is particularly useful in modeling missiles since missiles must remain co-positioned with the firing aircraft until launch. When an aircraft FOLLOW command is executed, all other maneuvering commands are cancelled. On execution of a subsequent maneuvering command, the FOLLOW command is cancelled and the aircraft retains the current position and velocity parameters.

Each aircraft in the simulation is capable of employing jammers which are turned on and off using profile commands. All jammers are initially off. A limitation of the program is that each aircraft may carry only one jammer of each type. Use of multiple jammers with the same parameters can be accomplished by defining different type jammers with identical specifications when building the data file. The flow diagram for Subroutine UPDAC is contained in Figure 8.

D. RADAR MODULE (UPDRD)

The radar subroutine is the heart of the FASTS program--all other program modules support it by either providing data inputs or processing its solutions for output. The subroutine evaluates aircraft position and aspect at each time interval and determines signal visibility. Logic flow is illustrated in Figure 9. The model considers antenna position, radar beam shape, atmospheric effects on attenuation and propagation, and relative position and power of each of the radar jammers.

Parameters for up to fifteen radar types are entered with the initial data file. Up to fifteen radar systems, with parameters of one of the radar types, may be fixed at any location or altitude on the x-y position grid. Co-location of radars is permitted. All radars radiate throughout the simulation; parameters and positions are held constant. Each antenna scans in a clockwise direction according to its input scan rate starting at the zero degree position.

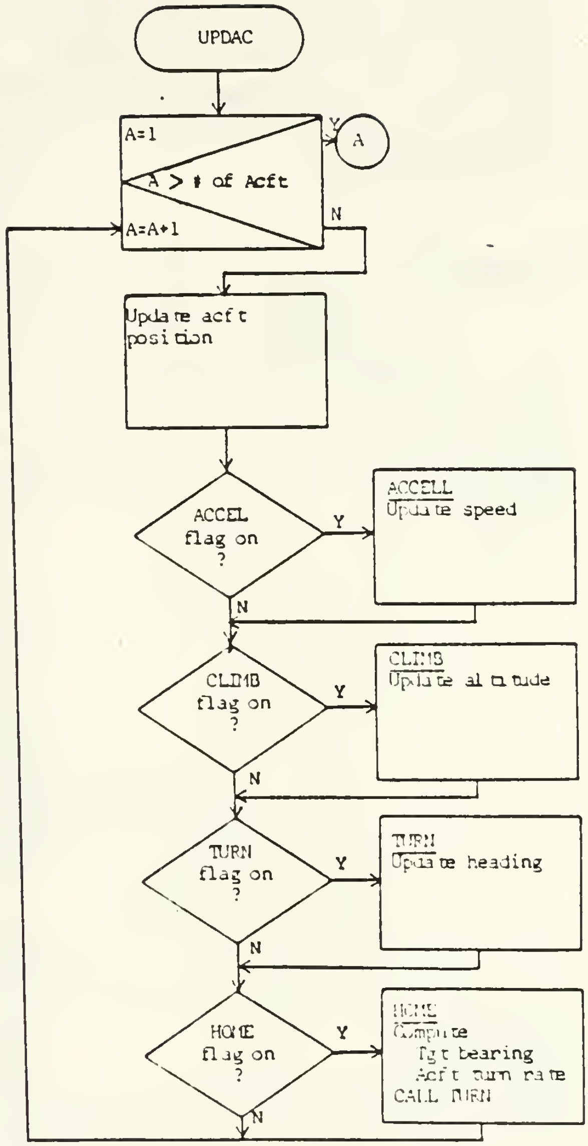

Figure 8a. Subroutine UPDAC

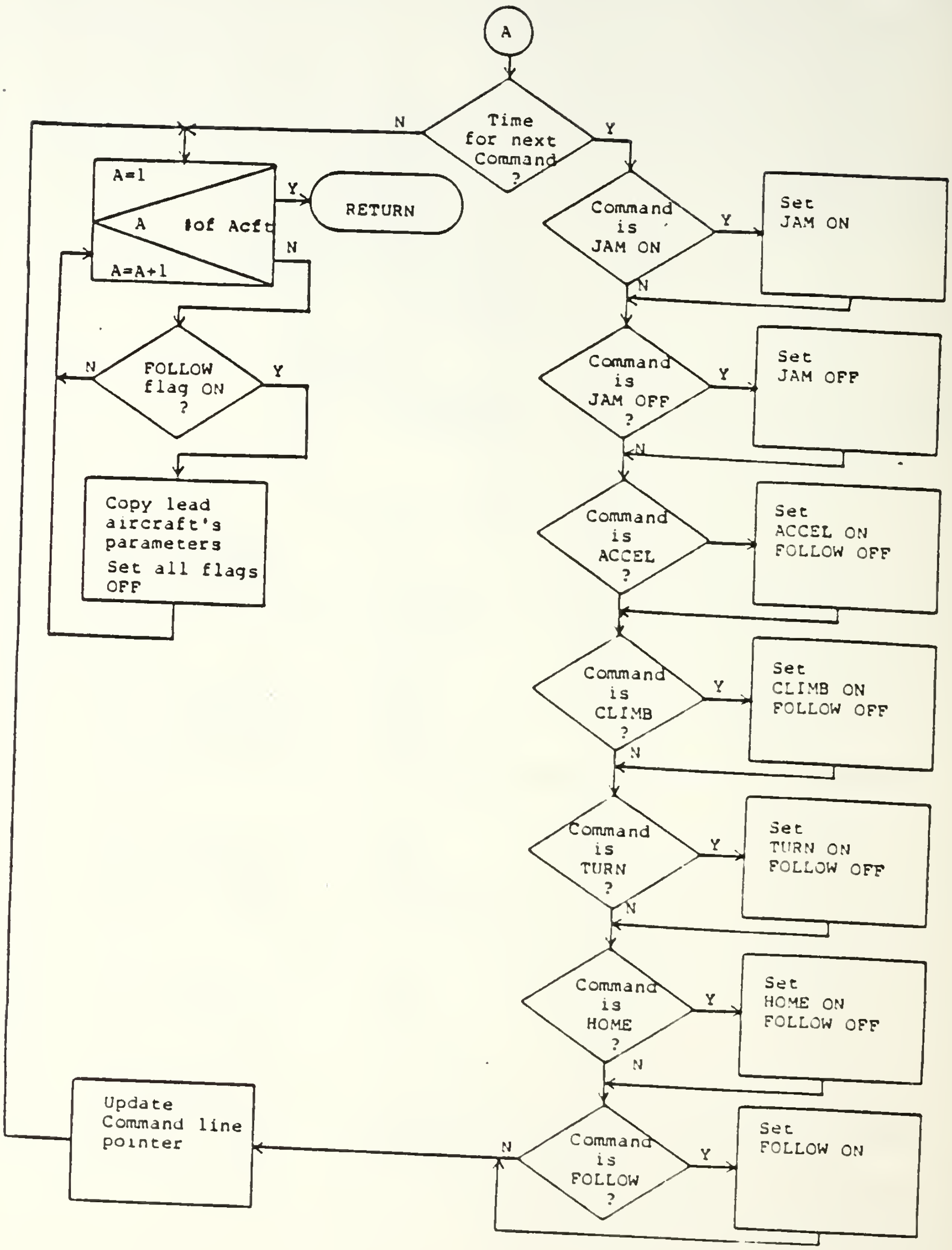

Figure 8b. Subroutine UPDAC (Cont'd)

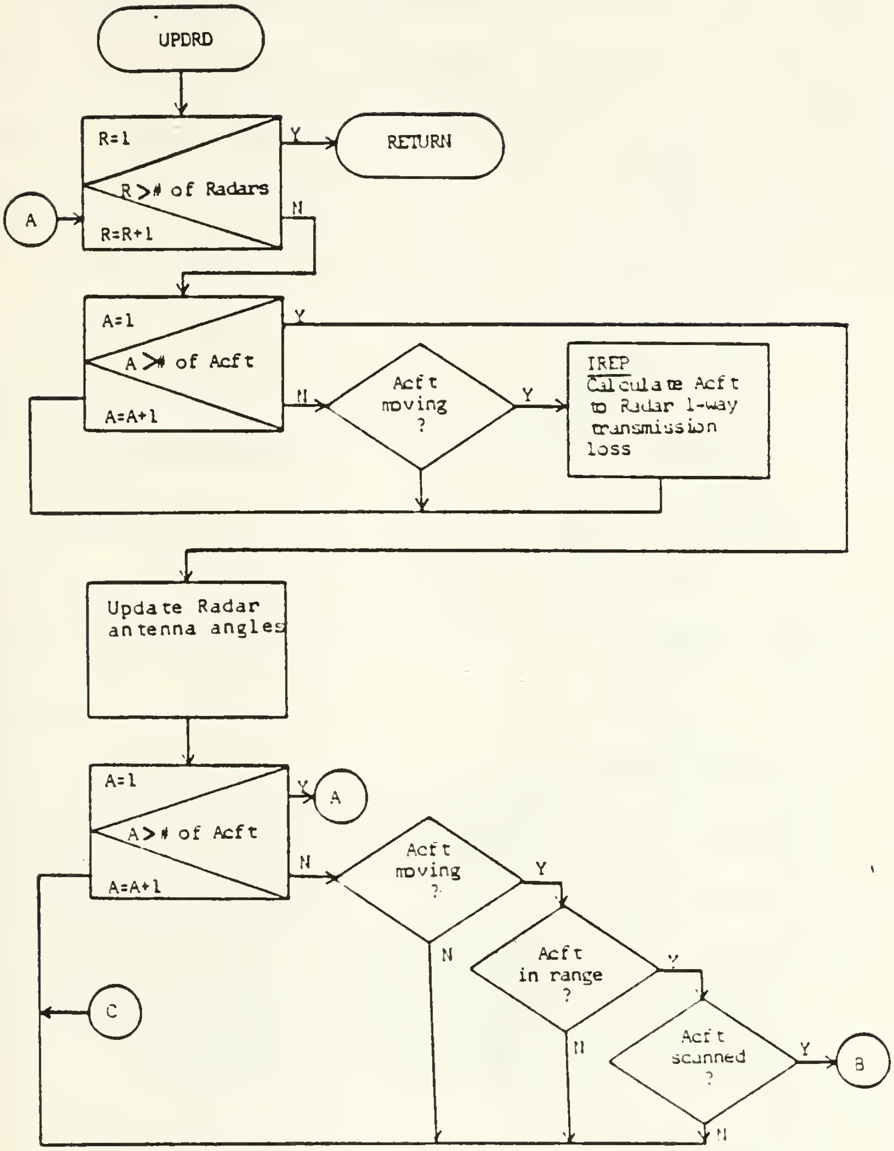

Figure 9a. Subroutine UPDRD

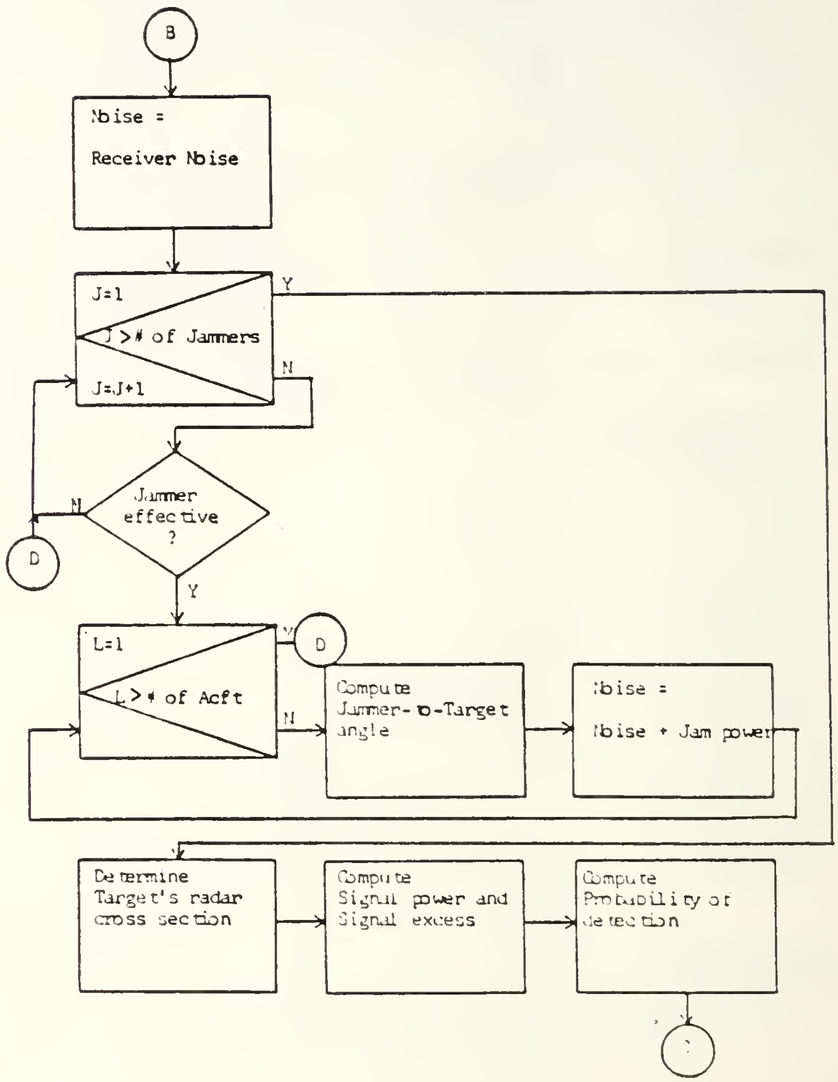

Figure 9b. Subroutine UPDRD (Cont'd)

Subroutine UPDRD evaluates detection probabilities considering each radar in turn.

1. Path Losses

One-way radar signal path losses are calculated between the site and each target using subroutine IREP. See Figure 10. The subroutine returns a value of the path loss obtained by dividing the loss-versus-range curve, Figure 4, into four sections and applying the appropriate formulas for each section. The first section extends from the radar site to the last range in the optical region where the direct and reflected waves are exactly in phase (RPEAK); the second, to the physical end of the optical region (OPMAX); the third, to the range at which the radar field attenuation becomes dominated by single mode diffraction and tropospheric scattering (DMIN); and the fourth section lies beyond.

Within the optical region, a spherical spreading wave model is used. Multipath effects caused by wave reflections off of a wind roughened surface and losses due to antenna vertical beam pattern are computed. At RPEAK, signal path losses are calculated to the maximum envelope of the interference null peaks. At ranges within the intermediate region between OPMAX and DMIN, loss is computed by linear interpolation. Beyond DMIN diffraction and troposcatter losses are calculated directly.

The FASTS subroutine IREP duplicates the loss module of the IREP Revision 2.2 program as closely as possible to

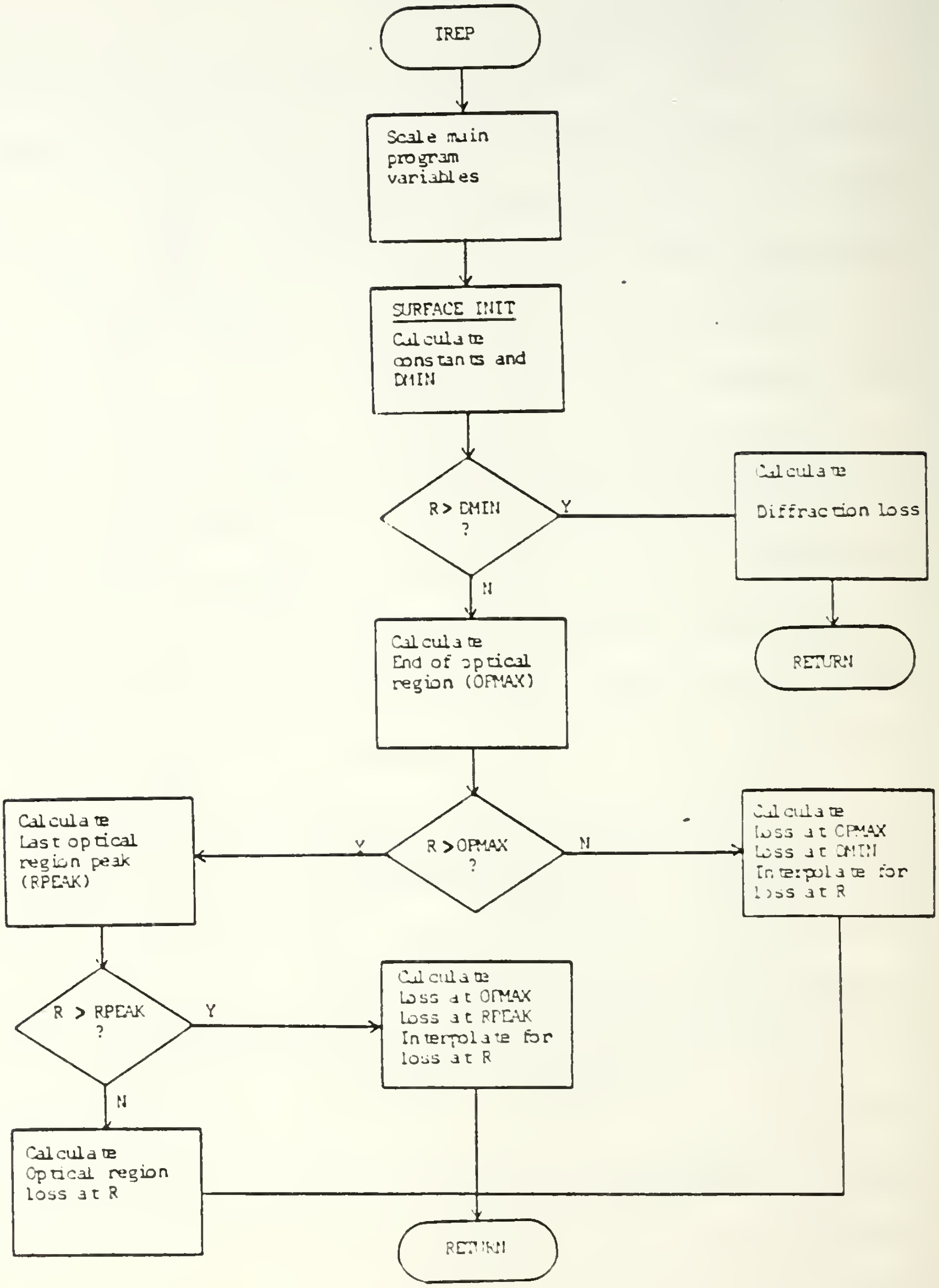

Figure 10. Subroutine IREP

permit future updating or modification. Variable names have been modified only to enable structural dovetailing with subroutine UPDRD and to prevent duplication of variable names. The one-way signal loss calculated by the IREPS program contains the radar equation factor for the antenna capture area, A_c, for an antenna of unity gain. Since the antenna capture area was already incorporated in the radar and jamming equations computed in subroutine IREP, the quantity:

$$A_c = \frac{\lambda^2}{4\pi} = \frac{c^2}{4\pi f^2}$$

was factored out of the IREP loss figure.

2. Noise Power

Noise power coupled into each receiver is computed by summing antenna thermal noise power and the noise power received from all aircraft jammers. Thermal noise power is computed as follows:

$$P_{no} = k\ T\ B_n\ F_n$$

where $k = 1.38E{-}23$ watt-sec/^{o}K (Boltzman's constant)

$T = 290^{o}$ K

B_n = Receiver noise bandwidth (Hz)

F_n = Receiver noise figure

The jamming power constants, (Jampwr) are computed in subroutine INIT and are equivalent to the quantity contained in the unbracketed portion of Equation (9). A polarization loss factor of two is assumed for all jammers. Power transmitted by each jammer is attenuated by the one-way IREP

loss figure and the sidelobe loss based on the angular displacement of the target aircraft from the jammer. FASTS contains methods, developed for JARSM, which compute the sidelobe loss for two general azimuth pattern shapes:

$$\left[\sin (x) / x\right]^2 \quad \text{and} \quad \left[\frac{\pi}{2} \; \frac{\cos(x)}{\pi/_2 - x^2}\right]^2$$

where x is the angle of displacement of the signal from the antenna axis in radians. These general forms are adjusted using the radar azimuth beamwidth and the level of the first sidelobe to approximate real antenna patterns. Figure 11 illustrates signal loss as a function of angular displacement for both antenna pattern forms.

3. Signal Power

The constant Rdreqn is computed in the INIT subroutine to represent the combined value of all radar equation factors excepting radar cross section, σ (meter^2), and the transmission loss factor. (Refer to Equation (8).) These additional quantities are position and aspect dependent and, therefore, are recomputed on each pass through subroutine UPDRD. The radar cross section is calculated by interpolation using the aircraft/radar aspect angle to enter a table of radar cross section values input via the data file. Since by reciprocity, the path from target to radar is the same as from radar to target, signal transmission loss is computed by doubling the one-way IREP loss figure.

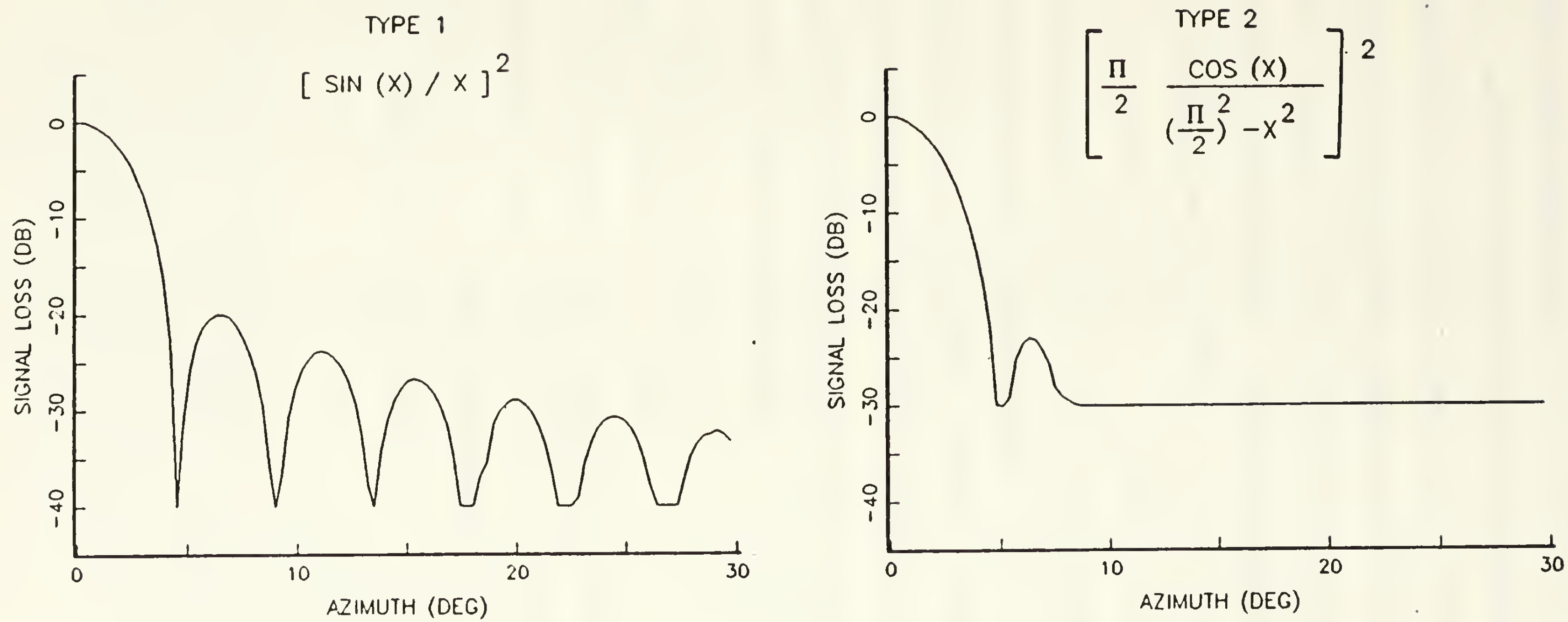

Figure 11. Radar Azimuth Antenna Patterns, Four Degree Beamwidth

4. Probability of Detection

Computation of the probability of detection for each aircraft/radar pair is made at each time increment. If the program determines that a radar has not scanned a particular aircraft, the associated probability is set to zero. Recall that the time increment can be no greater than the minimum radar scanning interval, and so it is quite possible to have incremental periods wherein the antenna axis of a radar does not cross all targets. If the aircraft is scanned by the radar, Equation (11) is used to determine the probability of detection based on the excess signal-to-noise ratio observed at the radar. The determination of the excess S/J ratio is made using the computed values for signal and noise power. The excess S/J ratio may be further reduced by a radar-specific visibility factor which shifts the value of the detection threshold to a value above unity. Figure 5 illustrates the visibility factor requirements for a representative radar system to achieve a 0.5 probability of detection. Note that the visibility factor is also a function of the selected probability of false alarm and the level of pulse integration. See Reference 7 for additional background.

E. PROGRAM OUTPUT

The subroutine Output processes simulation data at each iteration for direct output or for summary computations to be performed at the end of the simulation. Logic flow

diagrams for the subroutine are contained in Figure 12.

User selection of program output is made via interactive keyboard entry. Additionally the user is able to enter an output start time which determines the simulation time for the beginning of all output data displays and computations.

Four output formats are available. All output products can be printed or displayed on the CRT.

1. Data

Simulation data is printed for each aircraft following each time step iteration. Aircraft position coordinates, altitude, heading, speed, and radar detection probabilities can be sent to the CRT display or the system printer. The 80-column format of these displays limits output to simulations with four or fewer radar systems. The data output format is illustrated in Figure 13.

2. X-Y Plot

The X-Y Plot output selection displays a coordinate mapping of radar sites and aircraft positions throughout the simulation. The user selects plot coverage by entering coordinates for right, left, top, and bottom display boundaries. Aircraft movement tracks are displayed by solid or dotted lines reflecting susceptibility to detection by a selected radar system: A dotted line indicates a probability of detection less than 0.5; a solid line shows this threshold is met or exceeded. Normally all aircraft tracks are displayed in

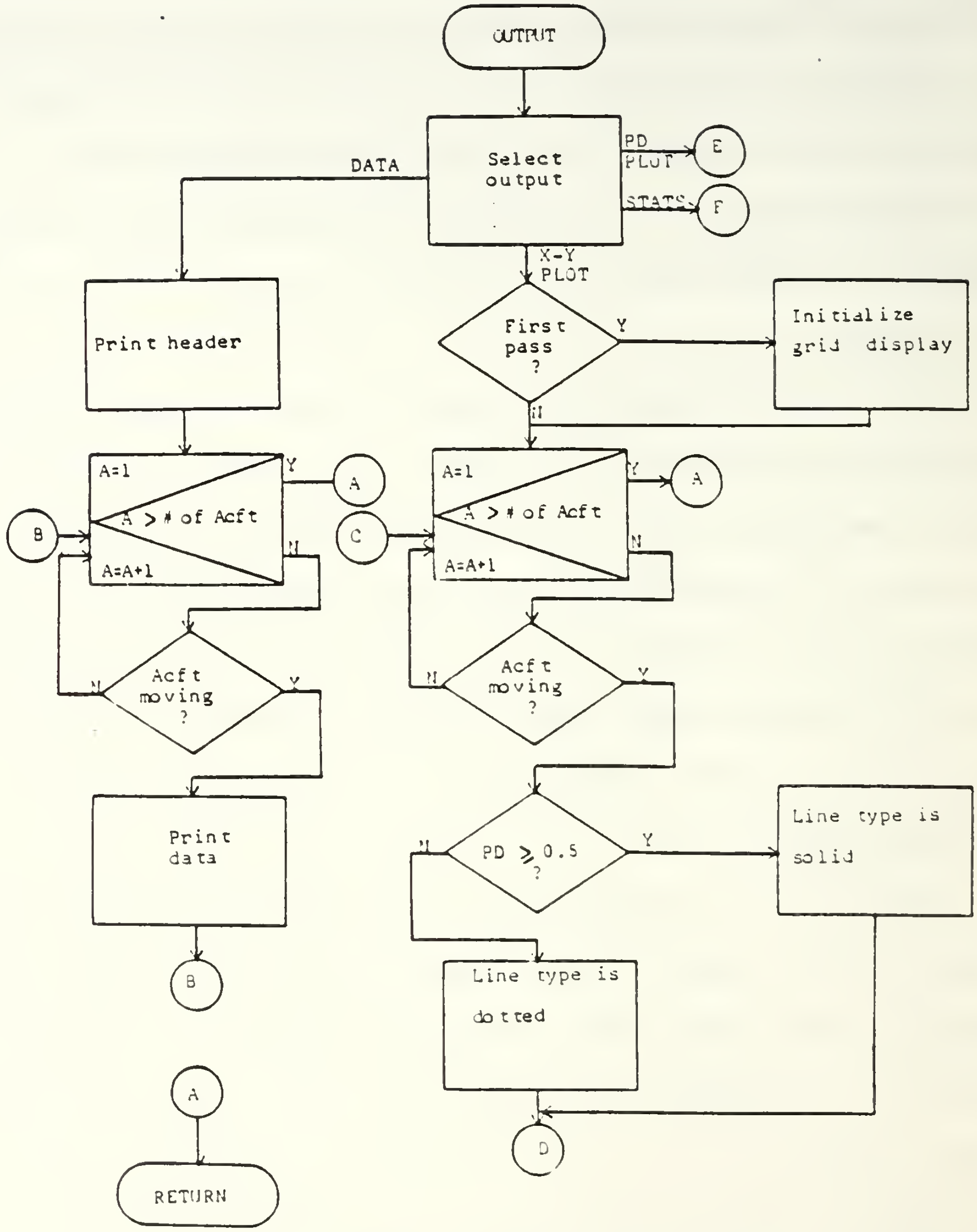

Figure 12a. Subroutine Output

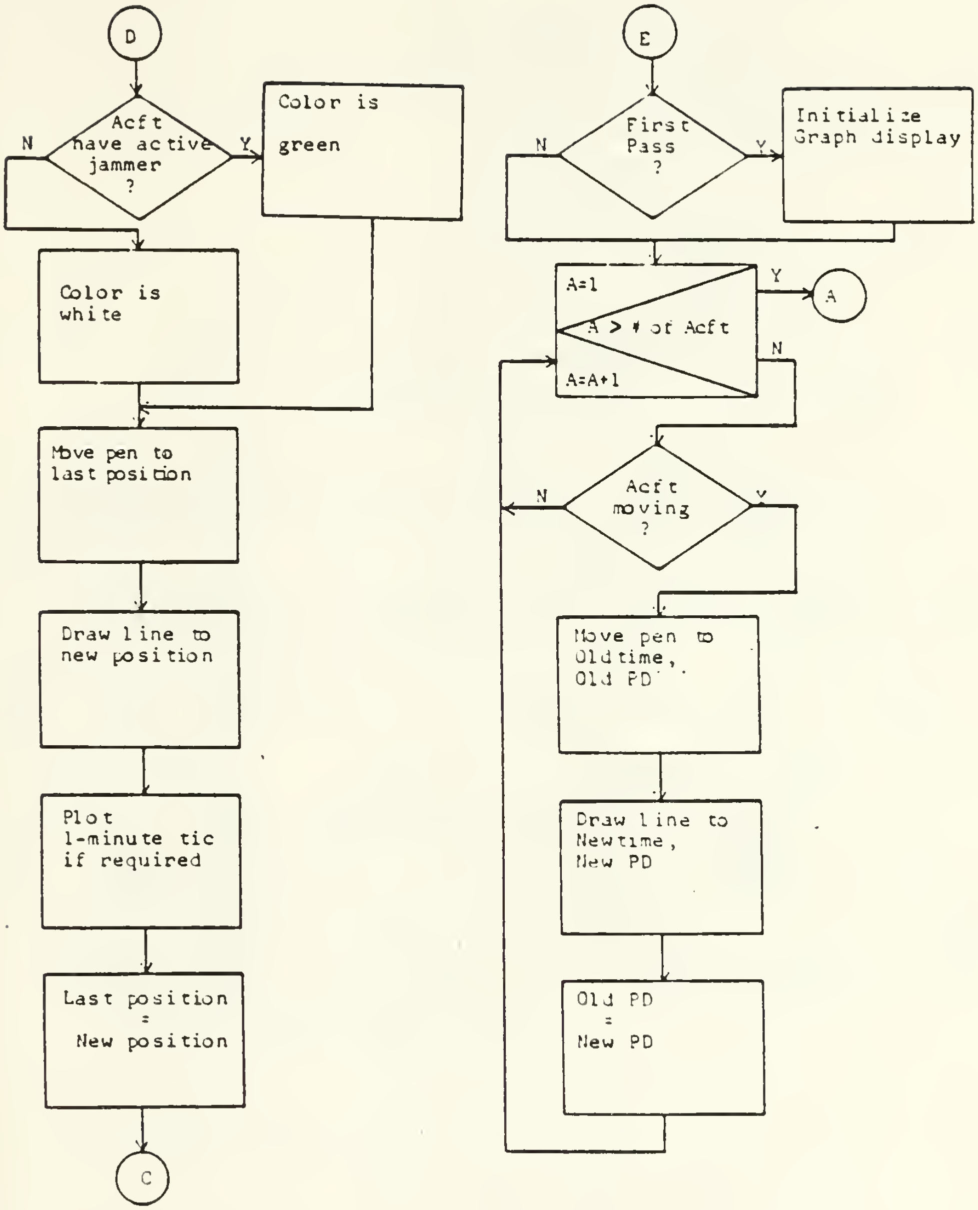

Figure 12b. Subroutine Output (Cont'd)

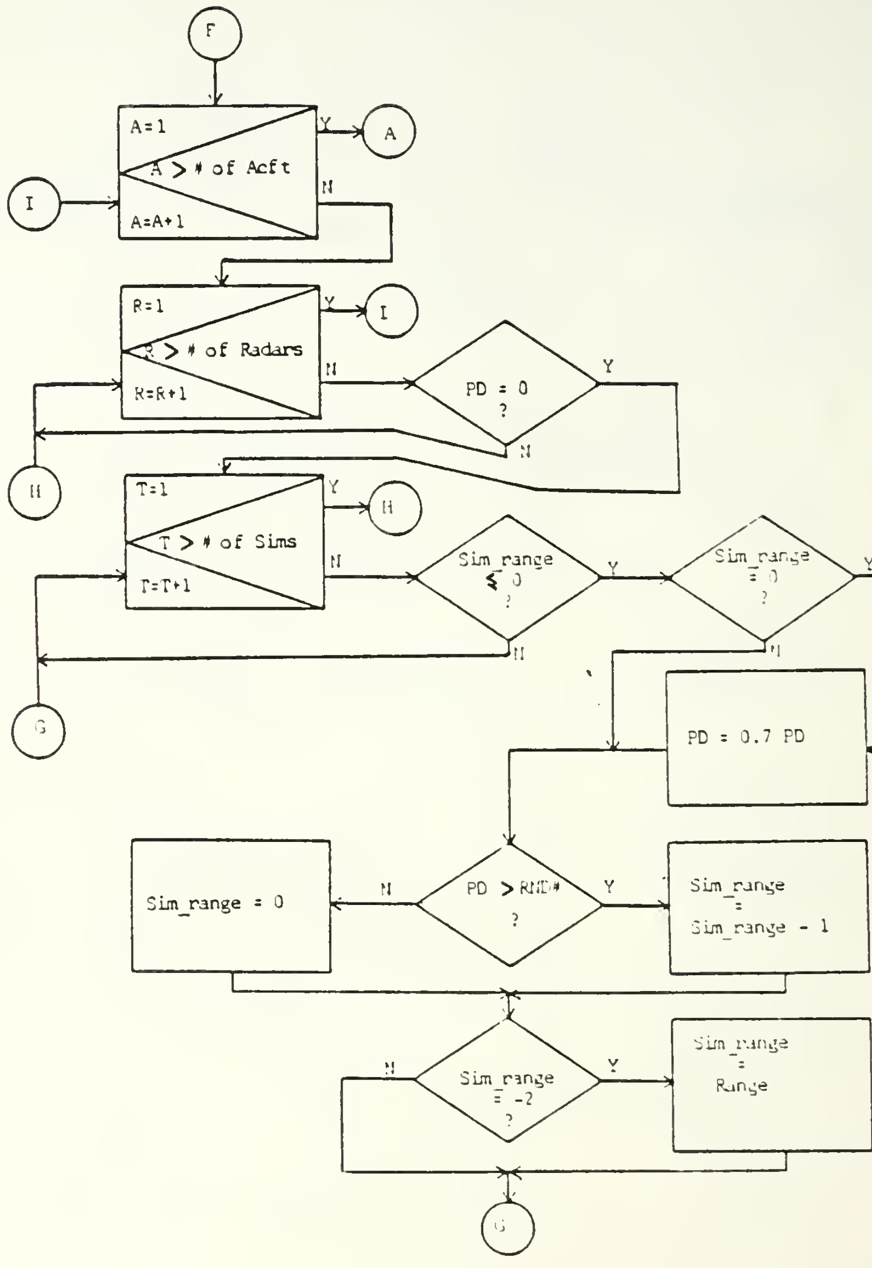

Figure 12c. Subroutine Output (Cont'd)

```
FASTS DATA OUTPUT            DATASET: SAMPLE

ACFT  TIME     DX      DY     ALT  HEADG  SPEED RADAR 1 RADAR 2

  1  110.0   52.7    71.0 5000.0  190.0  600.0   .9160  1.0000
  2  110.0   52.7    71.0 5000.0  190.0  600.0  0.0000   .9928

ACFT  TIME     DX      DY     ALT  HEADG  SPEED RADAR 1 RADAR 2

  1  115.0   51.8    71.0 5000.0  190.0  600.0   .9236  1.0000
  2  115.0   51.9    71.0 5000.0  190.0  600.0  0.0000  1.0000

ACFT  TIME     DX      DY     ALT  HEADG  SPEED RADAR 1 RADAR 2

  1  120.0   51.0    71.0 5000.0  190.0  600.0   .9279  1.0000
  2  120.0   51.0    71.0 5000.0  190.0  600.0  0.0000  1.0000
```

Figure 13. FASTS Data Output for Three Time Steps

white. Tracks for aircraft with jammers that are active against the selected radar are plotted in magenta. A sample of the X-Y Plot format is illustrated in Figure 14.

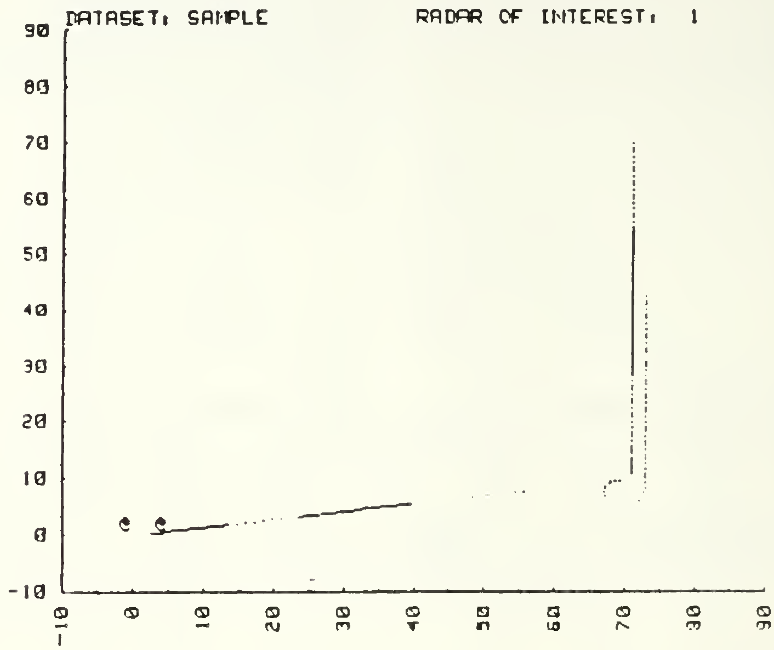

Figure 14. FASTS X-Y Plot Output

3. Probability of Detection per Scan Plot

The probability of detection per scan, P_d, for each aircraft by a selected radar is plotted against simulation time as depicted in Figure 15. The values for P_d, bounded by 0 and 1, are depicted on an unlabeled linear scale for each aircraft. The 0.5 probability of detection threshold reference is indicated by a dotted line for each aircraft. This plot

highlights time segments of high, low, or changing aircraft vulnerability to detection and permits comparative analysis between different aircraft and flight profiles. The user is cautioned not to interpret this to be a depiction of cumulative probabilities.

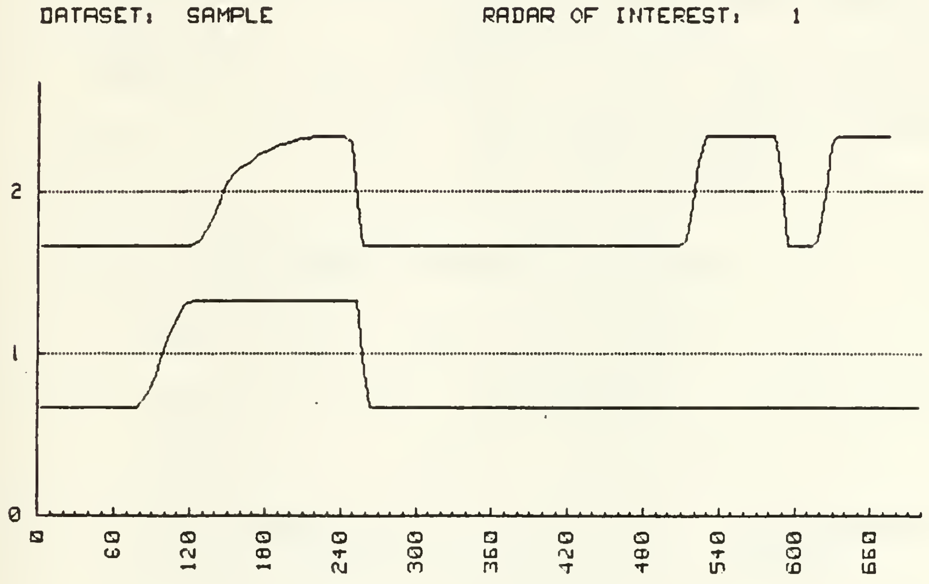

Figure 15. FASTS Probability of Detection per Scan Plot Output

4. First Detection Statistics

An estimate of the range of the first operator detection for each aircraft by each radar is made using statistical simulation and modeling of operator performance.

Throughout the program, fifty parallel detection simulations are maintained. At each iteration, if an aircraft is scanned, a random number, distributed uniformly on the interval (0.1), is drawn to support each of the fifty simulations. Using Equation (13), a detection is said to occur if the probabilities of detection on two successive scans exceed the random number drawn for each event. The probability of detection for the first of these two scans is reduced by thirty percent to compensate for the unalerted operator. If an operator detection is obtained, the range is recorded for later statistical computations. After the finish time has been reached, the fifty ranges are processed by subroutine Output-stats. See Figure 16. The ranges are sorted, and mean, standard deviation, and quantile statistics are computed over all simulations which experienced a detection. The percentage of simulations in which the aircraft was detected is computed as an estimator of an aircraft's probability of detection for the mission.

All statistics represent simulation events occurring after the user entered start time. The feature of start time selection allows the user to determine, for example, the range for the first operator detection of an aircraft following its descent to a low altitude where masking by the radar horizon occurs. In any case, first operator detection statistics can lose meaning if the aircraft is already detectable when the statistical computations are commenced.

A sample output for First-Detection Statistics is illustrated in Figure 17.

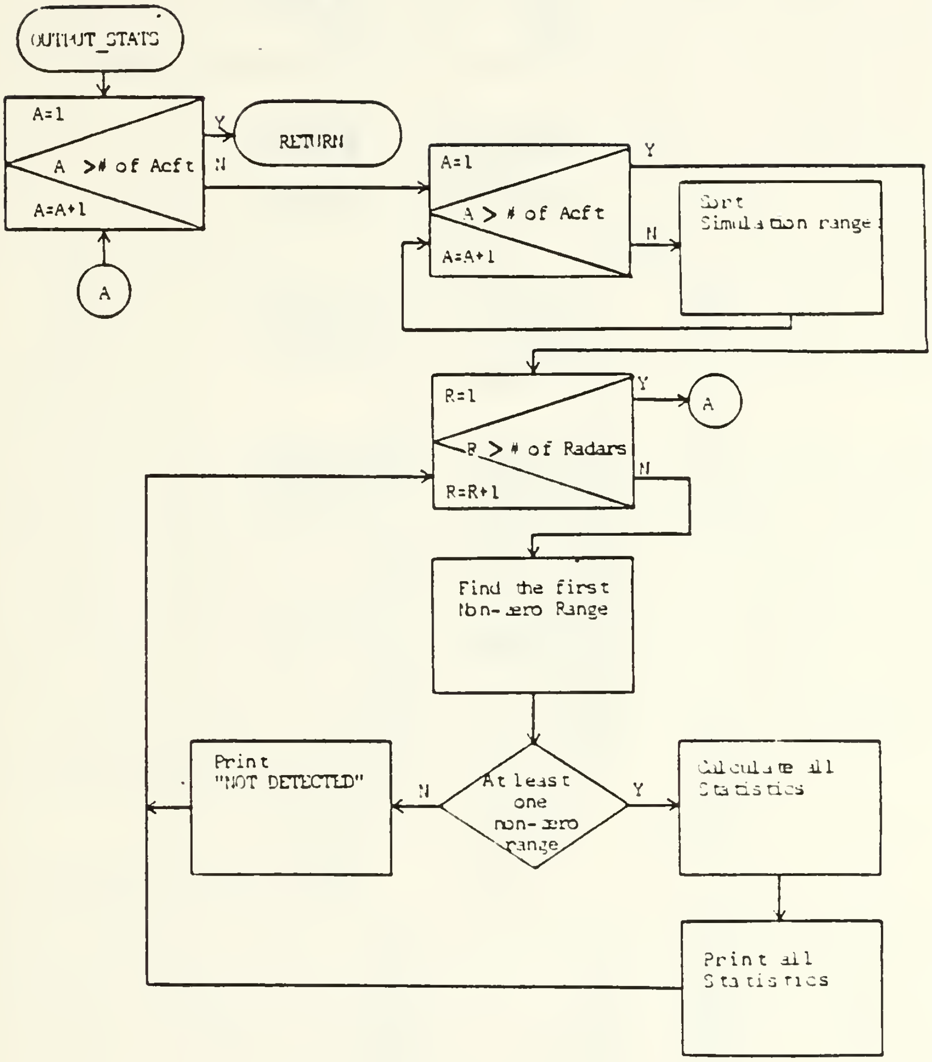

Figure 16. Subroutine Output-stats

```
FASTS STATISTICS OUTPUT                 DATASET: SAMPLE
START TIME:    400

AIRCRAFT  1          DETECTION RANGE STATISTISTICS
RADAR             MEAN    STD DEV   .25 QNT   .50 QNT   .75 QNT   PCT DET
 1             NOT DET    NOT DET   NOT DET   NOT DET   NOT DET         0
 2             NOT DET    NOT DET   NOT DET   NOT DET   NOT DET         0

AIRCRAFT  2          DETECTION RANGE STATISTISTICS
RADAR             MEAN    STD DEV   .25 QNT   .50 QNT   .75 QNT   PCT DET
 1              38.140       .945    37.140    38.390    38.390     1.000
 2              42.330      1.213    41.568    42.818    42.818     1.000
```

Figure 17. FASTS Statistics Output

IV. FASTS VERIFICATION

Considerable program verification was accomplished during the creation of the program. The proper operation of the data initialization, aircraft maneuvering, radar scanning and input/output features was confirmed as each module was assembled into the program. Variable tracing techniques and analysis of output data and graphics were used. To determine if FASTS was operating as intended, several aircraft/jammer flight profiles were simulated for which the results were easily predicted.

Verification of the radar simulation was accomplished by confirming proper operation of the environmental signal loss routine and analysis of the model output data with respect to aircraft detection at the radar horizon, jammer burnthrough ranges, and detection ranges for aircraft in a standoff jamming environment.

A. LOSS COMPUTATION TEST

Values for one-way signal transmission losses were traced for aircraft opening a radar site at altitudes of 500, 1000, and 5000 feet and compared with IREPS Revision 2.2 Loss Display data. Parameters for the AN/SPS-10 radar system and standard day atmospheric conditions were employed. The signal loss data compared within 2 dB for all three cases over ranges up to 160 nautical miles.

B. RADAR HORIZON TEST

FASTS simulations were conducted in which aircraft flew outbound from a radar site at 100, 200, and 500 feet. Using standard day atmospheric conditions and an antenna height of 100 feet, the last ranges at which the radar visibility threshold was exceeded were noted and found to be in agreement with the predicted theoretical radar horizon. Data for the tests are presented in Table 1 and Figure 18.

TABLE I
RADAR HORIZON TEST RESULTS

	Altitude (ft) 100	200	500	1000
Predicted Range (nm)	24.6	29.7	39.8	51.1
Observed Range (nm)	25	28	37	47

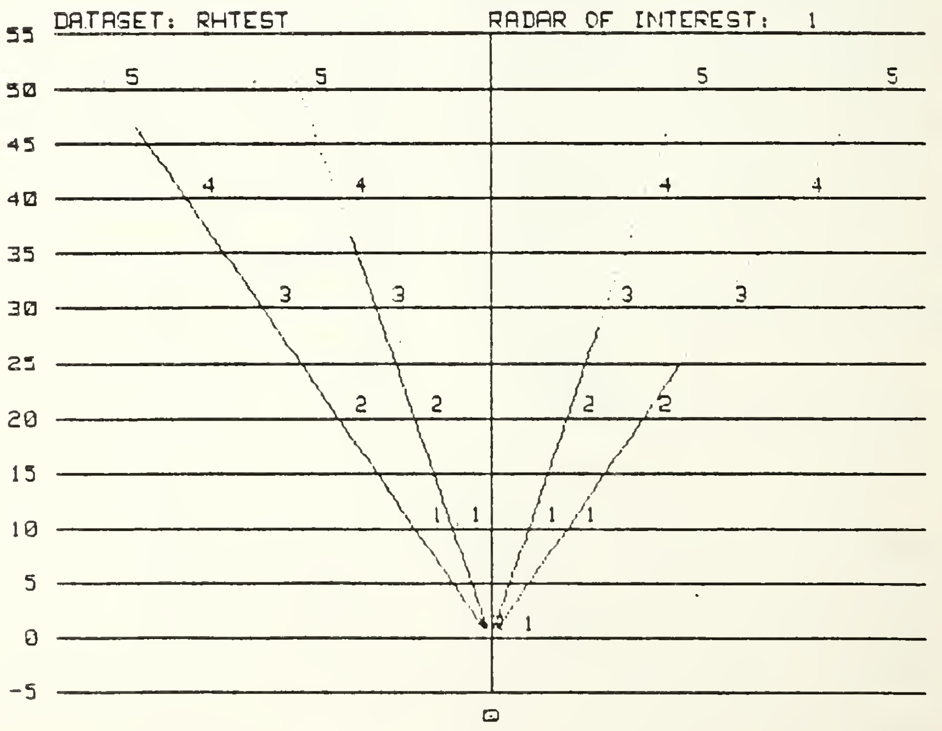

Figure 18. Radar Horizon Test

The deviation of the test results of up to eight percent from the predicted values are not considered to reflect any imprecision in the program. The radar horizon represents the end of the optical region beyond which the rate of signal attenuation shows a marked increase and, thus, is an upper bound approached by the ranges at which the returned power exceeds the radar's visibility threshold.

C. JAMMER SELF-SCREENING TEST

Two FASTS simulations were conducted in which aircraft carrying active jammers closed toward a radar site. The ranges at which the radar's visibility threshold was exceeded were compared with those predicted by equating the radar and jammer power equations (Equations (8) and (9)) and solving for range. The inherent assumptions for the equations of isotropic and non-reflected radiation were satisfied by a program modification setting the program variable for the pattern factor (FFAC) equal to unity. Results, presented in Table II, confirmed proper operation of noise power and detection probability computations.

D. STANDOFF JAMMER TESTS

1. Azimuth Test

Verification of the radar azimuthal antenna pattern modeling was accomplished through use of a multi-aircraft scenario. The jammer and twelve additional aircraft closed the target radar simultaneously from fifty nautical miles at

TABLE II
JAMMER SELF-SCREENING TEST RESULTS

	Simulation 1	Simulation 2
Predicted Range (nm)	17.03	35.26
Observed Range (nm)	17	35
Parameters:		
Pt (kw)	100	1000
Gt	10,000	10,000
Br (MHz)	0.5	0.1
Pj (kw)	0.8	14.0
Bj (MHz)	100	150
(m)	25	25

500 feet using one degree separation of inbound headings. The $(\sin x/x)^2$ azimuth antenna pattern--Type 1--with a four degree beamw dth and 20 dB loss in the first sidelobe was used. Figure 19 depicts the scenario and demonstrates the expected reduction of jammer protection afforded aircraft with increasing displacement from the jamming axis. Pattern nulls can also be discerned.

2. Range Test

This test was conducted to observe the effects of altitude, atmospheric ducting and jamming on the target range required to exceed the radar visibility threshold. An effective earth radius, k, of 3.92 and a duct height of 996 feet were used. In six simulations, targets flying at altitudes of 500 feet (in the duct) and 2000 feet (above the duct) closed a radar site. Jammer aircraft, when used, flew at 500 feet or 2000 feet, either with or directly above or below the target. The six simulations were repeated for standard day atmospheric conditions. The target observation ranges are presented in Table III.

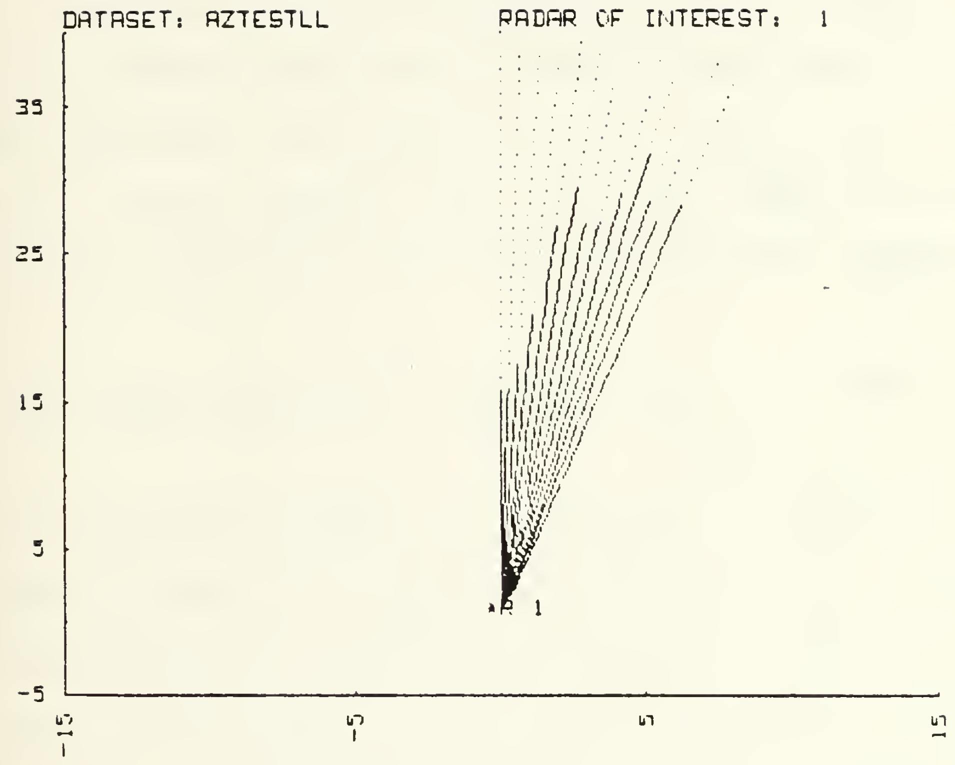

Figure 19. Standoff Jammer Test

TABLE III
RANGE TEST RESULTS

Target Altitude (ft)	Standard Day None	Standard Day Jammer Altitude 500 ft	Standard Day Jammer Altitude 2000 ft	Standard Day None	Standard Day Jammer Altitude 500 ft	Standard Day Jammer Altitude 2000 ft
500	34	17	15	>120	20	18
2000	62	55	28	93	46	29

Parameters:

Pt (kw)	100
Gt	10,000
Br (MHz)	0.5
Pj (kw)	0.8
Bj (MHz)	100
(m)	25

Without jamming and under standard day conditions, the targets were seen as they crossed their radar horizon ranges. Predictably, ducting extended the detection range for the low target and due to duct leakage effects, considerably extended the detection range for the target operating above the duct.

When jamming was employed, detection ranges were reduced in all cases.

The effect of locating the jammer within the duct is seen in an increased detection range (over that for nonducting conditions) for the target located within the duct which is caused by reduced transmission losses for both the radar and jammer signals. Reduced detection ranges for a target located above the duct are consistent with the increased jammer efficiency within the duct and the spherical propagation loss associated with the radar-to-target signal path.

When both the jammer and target are above the duct, detection ranges are shown to be nearly equal to those for standard day conditions, as expected, since spherical spreading laws are dominant.

Other verification tests are, no doubt, possible. However, these tests are sufficient to show that FASTS does perform accurately and consistently.

V. SAMPLE IMPLEMENTATION

An example of a tactical simulation is described in this chapter which includes a scenario definition, the initial tactical plan, the data file construction, a program execution outline and an analysis of the program output.

A. SCENARIO

In this example, FASTS is used to analyze an air strike against two ships located 300 nautical miles from base. The ships are defended by surface-to-air weapons, and so a standoff delivery of air-to-surface missiles (ASM's) is desired. Two ASM attack aircraft, one anti-radiation missile (ARM) aircraft, and a supporting tactical jammer aircraft are available.

The aircraft will proceed together toward the target at medium altitude (5000 feet) and descend to 1000 feet at 75 nautical miles from the target. At 50 nautical miles, the ASM aircraft split from the formation, turning 50 degrees right and left of the target bearing, and accelerate to attack speed. The ARM aircraft continues to close the target, fires his missile at 30 nautical miles, and retires. The jammer slows slightly, commences jamming, and establishes a figure-eight pattern at 30 nautical miles.

At 2 minutes and 35 seconds after the split, the first ASM aircraft turns left toward the ships, fires his missile

from 30 nautical miles at the rightmost ship, and turns to retreat. The second ASM aircraft turns right three minutes following the split, fires his missile from 30 nautical miles at the leftmost ship, and retires.

Near simultaneous impact of ASM's is desired; the ARM should arrive earlier to support the ASM's penetrating of the ships' radar defenses.

B. DATA FILE CONSTRUCTION

The data file is constructed as described in Appendix B. The listing is provided in Figure 20. Once constructed, the data file is easily modified to permit adjustment to the tactical scenario. The data file must be saved using the SAVE or RE-SAVE command in order to prevent loss of the file when the FASTS program is loaded.

C. PROGRAM EXECUTION

The source program is brought into the computer memory by entering the command LOAD "FASTS". On entering RUN, the program execution is begun, and the user is prompted to enter the data file name; the data file is retrieved and appended to the FASTS program. Following interactive queries to define the desired output form, the simulation is commenced.

The X-Y Plot output option is selected first and reviewed to verify the proper maneuvering geometry for the aircraft and proper radar positioning. Verification of the CLIMB and ACCEL commands is performed by reviewing the DATA

```
10 Dat !  DATASET NAME
20 DATA   WAS1
30 !
40 !IREPS    K        DUCT HT (FT)     WIND
50 DATA      1.33,      0,              8
60 !
70 !     NAC  NJM  NRD   NACTYP  NRDTYP   DT    TFIN
80 DATA  7,   2,   2,     2,       2,     10,   1000
90 !
100 Rdrdat:!
110 !          RDTYP    RDLAT    RDLONG    RDALT
120 DATA         1,       0,       0,        80      ! RDR 1
130 DATA         2,       0,       5,        80      ! RDR 2
140 !
150 !     RDSCNTYP    RDBTBTYP   RMAXTYP   RVZEROTYP
160 DATA    5,           0,        250,        0     ! RDR 1
170 DATA    5,           1,        125,        0     ! RDR 2
180 !
190 !
200 !     RDERPTYP   RDFRQTYP   RDGANTYP   RDFNTYP   RDNBWTYP   LOSSTYP
210 DATA   90,        1000,       40,        10,        .5,        10     ! RDR 1
220 DATA  102,         850,       35,         7,       0.1,         7     ! RDR 2
230 DATA   98,                    31
240 !
250 !
260 !     RDAZBWTYP  RDAZSLTYP  RDELBWTYP  CSCSQTYP  DTYPETYP    HPOLAR
270 DATA     4,        -20,         4,         0,        1,          1   ! RDR 1
280 DATA     3,        -20,         7,         0,        1,          1   ! RDR 2
290 DATA   3.5,        -20,         4,         1,        1,          0
300 !
```

Figure 20a. Data File Listing

```
310 Jmdat:!
320 !          JMBW    JMFRQ     JMERP
330 DATA   100,     1000,      800
340 DATA   150,      900,    14000
350 !
360 !
370 !      ALPHA     RCS
380 DATA     0,      14
390 DATA   180,      14
400 DATA   9999,     00.0
410 !
420 DATA     0,      -3
430 DATA   180,      -3
440 DATA  9999,       0
450 !
460 Acdat:!
470 !          ACTYPE    ACLAT    ACLONG    ACALT    ACHDG    ACVEL
480 DATA         1,      100,       0,     5000,     180,     360   ! JAMMER
490 DATA         1,      100,       0,     5000,     180,     360   ! SHOOTER(R)
500 DATA         1,      100,       0,     5000,     180,     360   ! SHOOTER(L)
510 DATA         1,      100,       0,     5000,     180,     360   ! SHOOTER(C)
520 DATA         2,      100,       0,     5000,     180,     360   ! MISSILE(R)
530 DATA         2,      100,       0,     5000,     180,     360   ! MISSILE(L)
540 DATA         2,      100,       0,     5000,     180,     360   ! MISSILE(C)
550 !
```

Figure 20b. Data File Listing (Cont'd)

```
560 !       TIME   CHANGE       X         Y
570 !ACFT1
580 DATA    1,       6,        3,        1
590 DATA  250,       4,     -100,     1000  ! DECEND TO 1000 FT
600 DATA  500,       3,       -5,      300  ! DECELL TO 300 KTS
610 DATA  500,       1,        1,        0  ! JAMMER 1 ON
620 DATA  500,       1,        2,        0  ! JAMMER 2 ON
630 DATA  740,       5,       -3,      181  ! TURN
640 DATA  860,       5,        3,      180  ! TURN
650 DATA  980,       5,        3,      045  ! TURN
660 DATA   9999
670 !
680 !ACFT2
690 DATA    1,       7,        1,        0  ! FOLLOW JAMMER
700 DATA  500,       3,        5,      420  ! ACCEL TO 420
710 DATA  500,       5,        3,      230  ! TURN
720 DATA  655,       6,        3,        1  ! HOME TO 1
730 DATA  740,       5,       -3,      360  ! TURN AFTER SHOT
740 DATA 9999
750 !
760 !ACFT3
770 DATA    1,       7,        1,        0  ! FOLLOW JAMMER
780 DATA  500,       3,        5,      420  ! ACCEL TO 420
790 DATA  500,       5,       -3,      130  ! TURN
800 DATA  680,       6,        3,        2  ! HOME TO 2
810 DATA  750,       5,       -3,      360  ! TURN AFTER SHOT
820 DATA 9999
830 !
```

Figure 20c. Data File Listing (Cont'd)

```
840 !ACFT4
850 DATA    1,      7,        1,       0  ! FOLLOW JAMMER
860 DATA  500,      3,        5,     360  ! MAINTAIN 360 KTS
870 DATA  700,      5,       -3,     360  ! TURN AFTER SHOT
880 DATA 9999
890 !
900 !ACFT5
910 DATA    1,      7,        2,       0  ! FOLLOW SHOOTER(R)
920 DATA  730,      6,        3,       1  ! HOME TO RDR 1
930 DATA  730,      3,       50,     550  ! ACCEL
940 DATA  730,      4,     -100,      50  ! FALL  TO 50 FT
950 DATA 9999
960 !
970 !ACFT6
980 DATA    1,      7,        3,       0  ! FOLLOW SHOOTER(L)
990 DATA  740,      6,        3,       2  ! HOME TO RDR 2
1000 DATA  740,     3,       50,     550  ! ACCEL
1010 DATA  740,     4,     -100,      50  ! FALL  TO 50 FT
1020 DATA 9999
1030 !
1040 !ACFT7
1050 DATA    1,     7,        4,       0  ! FOLLOW SHOOTER(C)
1060 DATA  700,     6,        3,       1  ! HOME TO RDR 1
1070 DATA  700,     3,       50,     750  ! ACCEL
1080 DATA  700,     4,     1000,   10000  ! CLIMB TO 10000 FT
1090 DATA 9999
```

Figure 20d. Data File Listing (Cont'd)

output information. If the simulation is seen to be operating properly, the X-Y Plot figure may be sent to the printer. Figures 21 through 24 represent plots of the strike for 100 and 50 mile ranges displaying visibility thresholds for each radar.

The program is run again, and the Probability of Detection Plot output is selected. Graphs are printed showing the probability of detection for each aircraft relative to each radar system. (See Figures 25 and 26.)

The first Detection Statistics output is obtained on the final run. The initiation time for the statistics compliation is chosen to be twenty seconds after the launch of the second ASM to allow both missiles to fall below their radar horizon altitudes. Figure 27 contains the statistics output for the missiles, i.e., aircraft 5, 6, and 7.

D. EVALUATION OF RESULTS

Analysis of the X-Y Plot and Probability of Detection per Scan Plot shows the strike group would almost certainly have been acquired by enemy radars and tracked from the radar horizon at 90 miles until they descended at 75 miles. Jamming protection after the formation split at 50 miles only provided 50 to 80 seconds of coverage for the ASM aircraft due to their increasing displacement from the jamming axis. The ASM aircraft should expect to be tracked continuously by both ships from this burnthrough point through weapon delivery and their outbound turn maneuver.

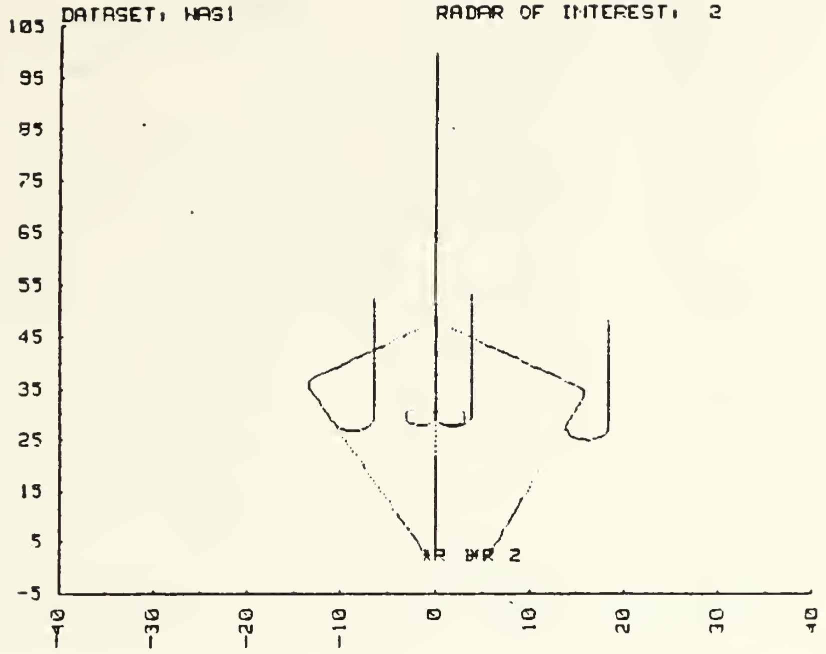

Figure 21. X-Y Plot for Radar 1; 105 nm Range

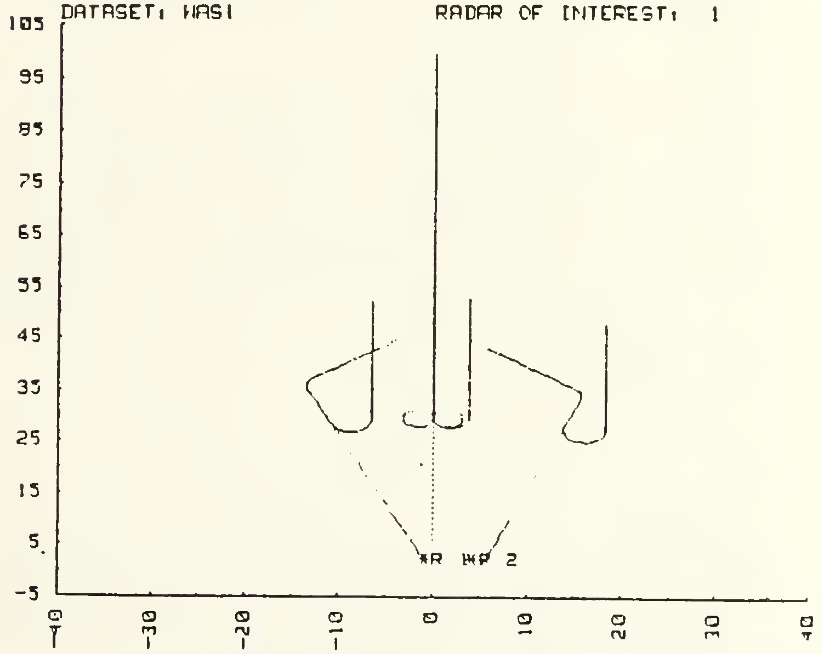

Figure 22. X-Y Plot for Radar 2; 105 nm Range

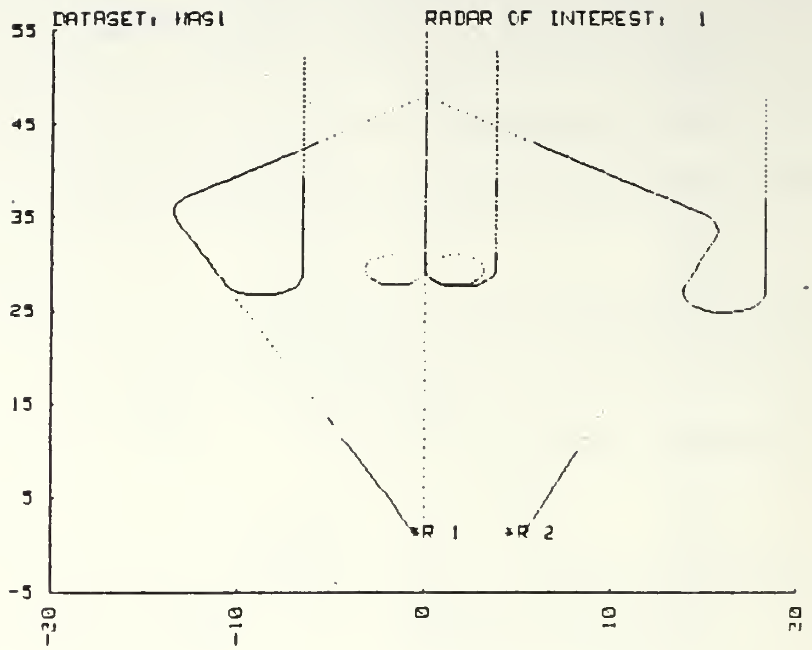

Figure 23. X-Y Plot for Radar 1; 55 nm Range

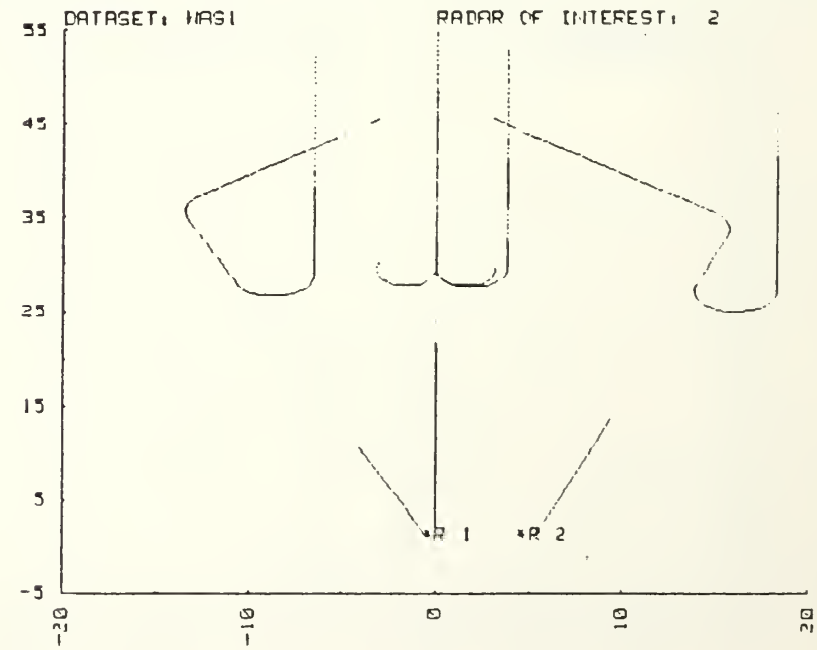

Figure 24. X-Y Plot for Radar 2; 55 nm Range

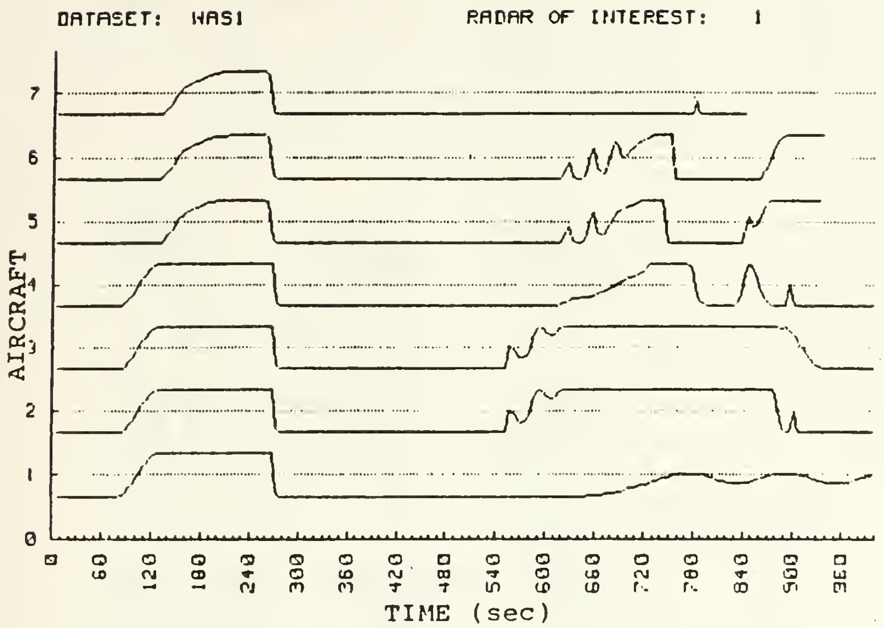

Figure 25. Probability of Detection per Scan Plot for Radar 1

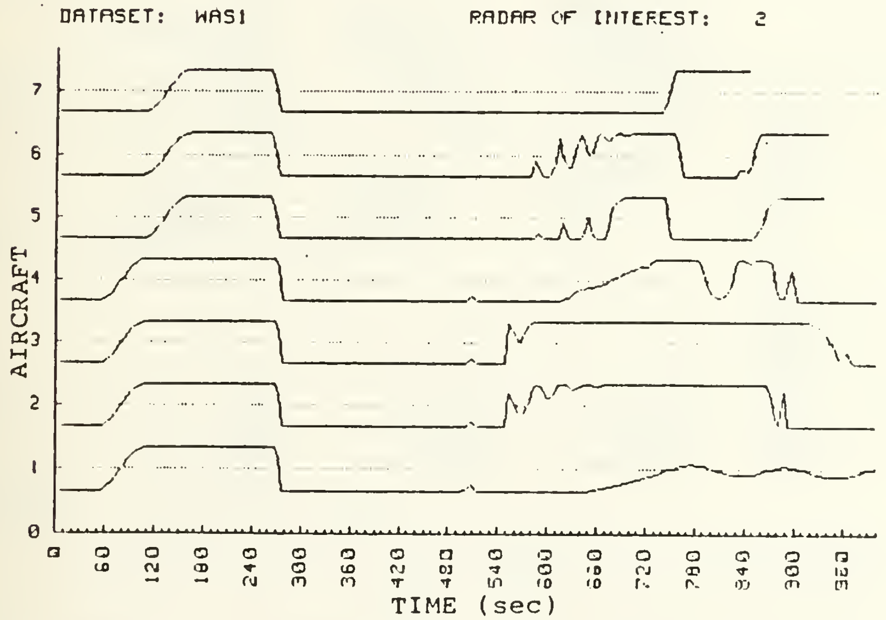

Figure 26. Probability of Detection per Scan Plot for Radar 2

FASTS STATISTICS OUTPUT DATASET: WAS1

START TIME: 760

AIRCRAFT 5 DETECTION RANGE STATISTISTICS

RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET
1	11.762	1.674	10.907	11.670	13.198	1.000
2	14.342	.749	13.900	14.260	14.622	1.000

AIRCRAFT 6 DETECTION RANGE STATISTISTICS

RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET
1	11.605	.923	10.713	11.403	12.101	1.000
2	14.399	.963	13.781	14.163	14.545	1.000

AIRCRAFT 7 DETECTION RANGE STATISTISTICS

RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET
1	NOT DET	NOT DET	NOT DET	NOT DET	NOT DET	0
2	18.541	.323	18.260	18.762	18.762	1.000

Figure 27. First Detection Statistics for Simulated Missiles

Due to his close alignment with the jamming axis, the ARM aircraft probably would not be detected by either ship's radar until just prior to launching his missile. Radar tracking would be solid through his outbound turn but would then degrade rapidly.

Both ASM's can be seen to be covered by jamming until well within their theoretical radar horizon of 19.7 miles. The statistical simulation predicts mean detection ranges for the ASM's of 11.8 and 11.6 miles by radar 1. Radar 2 ranges, 14.3 and 14.4 miles, were slightly higher due to the missiles' displacement from the jammer axis.

The ARM would not have been detected by radar 1; radar 2 may have detected the missile at as far as 18 nautical miles (from ship 2) when it would have been about 90 seconds from impact.

Missile coordination was satisfactory with ASM's impacting their targets with eight seconds separation following the arrival of the ARM by 1 minute and 32 seconds.

E. FOLLOW-ON SIMULATIONS

With the above results serving as a baseline, the scenario data file now can be modified to investigate and compare alternative plans or conditions. Such easily incorporated changes might include:

- Reduced altitudes for ASM launching aircraft
- Jammers accompanying ASM launching aircraft
- Different relative positionings of enemy ships
- Non-standard atmospheric conditions

VI. RESULTS AND CONCLUSIONS

The FASTS program developed in this thesis provides a consistent tool for use in the tactical planning process. It has demonstrated potential utility for: designing and simulating plans for coordinated tactical strikes; investigating radar visibility of aircraft under both standard and anomolous propagation conditions; and evaluating the effect of jamming on aircraft detection in a dynamic scenario.

Certain limitations exist in FASTS which must be recognized by a user in order to properly interpret the simulation results. Specifically, FASTS does not model:

1. Ship motion or the effect of wind which could easily alter the critical relative geometry of the simulation elements;

2. Radar transmission loss for targets above 10,000 feet altitude with verified accuracy;

3. Effects of jammer antenna blanking caused by maneuvering of the jammer aircraft;

4. Radar returns from sea clutter, an effect enhanced under ducting conditions, which may greatly reduce an operator's ability to discern an otherwise detectable target.

Areas for potential improvement to FASTS which could provide an increased simulation capability include incorporation of:

1. A standardized data base to include parameters for aircraft, radars, and jammers;

2. Missile profile routines to assess launch parameters and determine missile flight path vectors.

3. Transmission loss modeling for targets above 10,000 feet altitude;

4. Techniques for optimizing jammer placement as developed by T.W. White [Ref. 11] as a potential maneuvering control for jammer aircraft; and

5. Streamlined data and computation routines.

It is hoped that any future development effort for FASTS will not lose sight of its original objective--to provide a tactics testbed which can be used easily and interpreted by a fleet tactics planner. Evolution into a stockastic battle model would beget an increased level of complexity contrary to its intent.

APPENDIX A. FASTS PROGRAM SOURCE CODE

```
10 !           -=*** Fleet Anti-Ship Tactics Simulator ***=-
20 !
30 ! FASTS supports the evaluation of a many-on-many scenario involving
40 ! strike aircraft, support jammers, and air search radars.  It is
50 ! essentially a geometric model that computes the probability of
60 ! a radar's detecting a target aircraft as a function of the S/J ratio
70 ! observed at the radar receiver.  The program draws directly from both
80 ! the Modified Jammimg Aircraft and Radar Simulation (JARSM) Program/
90 ! Johns-Hopkins Univ. APL and NOSC's IREPS radar loss model.
100 !
110 ! ********************************************************************
120 ! BEGIN FASTS
130 ! *********************************************************************
140 !
150 OPTION BASE 1
160 !
170 INTEGER Nac,Njm,Nrd,Nsi,Nactyp,Ncp
180 INTEGER Actype(15),Alpha(15,360),Ndeg(15),Change(15,15)
190 INTEGER Cmmd(15),Acx(15,15),Acy(15,15),Dtype(15,2),Atsite(15)
200 INTEGER Rdtyp(15),Nrdtyp,Output_choice,Rdr_choice,Rule,Hpolar(15,2)
210 INTEGER Tc,Rdno
220 INTEGER Index(15,360),Ndeg
230 INTEGER A,I,J,K,M,Q,Qq,R,Tt
240 !
250 ! INTEGER VARIABLES USED AS LOGICAL TYPES
260 INTEGER Accl(15),Clmb(15),Turn(15),Hhom(15),Cscsq(15,2),Cross
270 INTEGER Jamac(15,15),Nojam(15,15),Rdbtbtyp(15),Rdbtb(15),Scanned(15,15)
280 INTEGER Graphics_flag,Ship_flag(15),Follow(15),Stopnext(15)
290 !
```

```
300 REAL Aclat(15),Aclong(15),Acalt(15),Acvel(15),Achdg(15),Hdlat(15)
310 REAL Hdlong(15)
320 REAL Acaccl(15),Acclmb(15),Acturn(15),Taccl(15),Tturn(15)
330 REAL Tclmb(15),Rcs(15,360),Clock(15,15)
340 REAL Jmbdw(15),Jmfrq(15),Jmerp(15),Jmpol(15),Jmeff(15,15)
350 REAL Rderptyp(15,2),Rdfrqtyp(15),Rdgantyp(15,2),Rdfntyp(15)
360 REAL Rdnbwtyp(15),Losstyp(15),Rdscantyp(15),Rmaxtyp(15),Rvzerotyp(15)
370 REAL Rdalt(15),Rdart(15),Rdlat(15),Rdlong(15)
380 REAL Rdant(15,2),Rderp(15,2),Rdfrq(15),Rvzero(15)
390 REAL Rdgan(15,2),Rdfn(15),Rdmxt(15),Rdnbw(15),Rdscn(15)
400 REAL Rmax(15),Loss(15),Rdazbw(15,2),Rdazsl(15,2),Phi0(15,2)
410 REAL Rate(10),Deg_scanned(15),Exp2(15),Rdreqn(15,2),Jampwr(15,2,15)
420 REAL R(15),Rr(15),H4(15),Phi(15),Theta(15)
430 REAL Plval(2),Fstlob(2),Seclob(2),Farlob(2),Xzero1(2),Xzero2(2)
440 REAL X3db(2),Coeff(2,3),X1(2),X2(2)
450 REAL Array(15,360),Irep_loss(15,2)
460 REAL Buffr(15,21),Old_buffr(15,21),Sim_rng(15,15,50)
470 !
480 ON ERROR GOTO Endit
490 GOTO Dsn ! APPEND DATASET TO PROGROM SOURCE CODE
500 !
510 Main: !      -=*** Main Program ***=-
520 !
530 GOSUB Init
540 GOSUB Setup
550 Stepclock:  T=T+Dt
560 IF T Tfin OR T 9999 THEN  GOTO Exit
570 GOSUB Updac
580 GOSUB Updrd
590 GOSUB Outpt
600 GOTO Stepclock
610 !
620 !   -=*** End Main Program ***=-
```

```
300 REAL Aclat(15),Aclong(15),Acalt(15),Acvel(15)
310 REAL Achdg(15),Hdlat(15),Hdlong(15)
320 REAL Acaccl(15),Acclmb(15),Acturn(15),Taccl(15),Tturn(15)
330 REAL Tclmb(15),Rcs(15,360),Clock(15,15)
340 REAL Jmbdw(15),Jmfrq(15),Jmerp(15),Jmpol(15),Jmeff(15,15)
350 REAL Rderptyp(15,2),Rdfrqtyp(15),Rdgantyp(15,2),Rdfntyp(15)
360 REAL Rdnbwtyp(15),Losstyp(15),Rdscantyp(15),Rmaxtyp(15),Rvzerotyp(15)
370 REAL Rdalt(15),Rdart(15),Rdlat(15),Rdlong(15)
380 REAL Rdant(15,2),Rderp(15,2),Rdfrq(15),Rvzero(15)
390 REAL Rdgan(15,2),Rdfn(15),Rdmxt(15),Rdnbw(15),Rdscn(15)
400 REAL Rmax(15),Loss(15),Rdazbw(15,2),Rdazsl(15,2),Phi0(15,2)
410 REAL Rate(10),Deg_scanned(15),Exp2(15),Rdreqn(15,2),Jampwr(15,2,15)
420 REAL R(15),Rr(15),H4(15),Phi(15),Theta(15)
430 REAL Plval(2),Fstlob(2),Seclob(2),Farlob(2),Xzero1(2),Xzero2(2)
440 REAL X3db(2),Coeff(2,3),X1(2),X2(2),Sim_rng(15,15,50)
450 REAL Array(15,360),Irep_loss(15,2),Buffr(15,21),Old_buffr(15,21)
460 !
470 ON ERROR GOTO Endit
480 GOTO Dsn ! APPEND DATASET TO PROGROM SOURCE CODE
490 !
500 Main:!      -=*** Main Program ***=-
510 !
520 GOSUB Init
530 GOSUB Setup
540 Stepclock   T=T+Dt
550 IF T Tfin OR T 9999 THEN  GOTO Exit
560 GOSUB Updac
570 GOSUB Updrd
580 GOSUB Outpt
590 GOTO Stepclock
600 !
610 !   -=*** End Main Program ***=-
```

```
620 !
630 Dsn: ! APPEND DATA SET
640 PRINTER IS CRT
650 PRINT PAGE
660 GINIT
670 GRAPHICS OFF
680 ! APPEND DATA SET FILE TO PROGRAM SOURCE CODE.
690 DISP "ENTER DATASET FILE NAME:  "
700 ENTER KBD;Ds_name$
710 PRINT TABXY(1,20);"LOADING DATASET FILE:  ";Ds_name$;
720 DISP
730 GET Ds_name$,Dat
740 GOTO Main
750 !
```

```
760 Init  ! -=***INITIALIZE PROGRAM NON-ZERO VARIABLES***=-
770 RANDOMIZE 92847
780 C=.161880  !  NM PER SEC / 1.0 E-6
790 Pid180=PI/180
800 D180pi=180./PI
810 Gfac=2/3
820 Graphics_flag=0
830 Zero=0
840 Rdr_choice=16
850 Ncp=15  !  MAX NUMBER OF FLIGHT COMMAND PROCEDURES FOR EACH AIRCRAFT
860 READ Plval(*) ! ANTENNA HORIZ BEAM MODELING PARAMETERS
870 DATA 1.0,0.40526
880 READ Fstlob(*)
890 DATA -13.27,-23.1
900 READ Seclob(*)
910 DATA -30,-30
920 READ Farlob(*)
930 DATA -35,-35
940 READ Xzero1(*),Xzero2(*)
950 DATA 1,1.5,2,2.5
960 READ X3db(*)
970 DATA 1.39156,1.8677
980 Coeff(1,1)=0.00348
990 Coeff(2,1)=0.0000764
1000 Coeff(1,2)=-0.047831
1010 Coeff(2,2)=-0.001292
1020 Coeff(1,3)=0.16522
1030 Coeff(2,3)=0.005657
1040 READ X1(*),X2(*)
1050 DATA 1.875,2.25,      2.25,2.75
1060 !
```

```
1070 ! DATA FOR FOLLOWING 'READ' STATEMENTS AT END OF PROGRAM (LABEL: DAT)
1080 READ Ds_name$
1090 PRINT "DATASET    ";Ds_name$
1100 WAIT 2
1110 READ Kfac,Ht_ductft,Wind
1120 READ Nac,Njm,Nrd,Nactyp,Nrdtyp,Dt,Tfin
1130 FOR R=1 TO Nrd ! READ RADAR TYPE AND POSIT DATA
1140   READ Rdtyp(R),Rdlat(R),Rdlong(R),Rdalt(R)
1150 NEXT R
1160 !
1170 ! READ PARAMETERS FOR EACH RADAR TYPE
1180 FOR R=1 TO Nrdtyp
1190   READ Rdscntyp(R),Rdbtbtyp(R),Rmaxtyp(R),Rvzerotyp(R)
1200 NEXT R
1210 FOR R=1 TO Nrdtyp
1220   READ Rderptyp(R,1),Rdfrqtyp(R),Rdgantyp(R,1),Rdfntyp(R),Rdnbwtyp(R),Los
styp(R)
1230   IF Rdbtbtyp(R)=1 THEN READ Rderptyp(R,2),Rdgantyp(R,2)
1240 NEXT R
1250 Q=1
1260 FOR R=1 TO Nrdtyp
1270   READ Rdazbwtyp(R,Q),Rdazsltyp(R,Q),Rdelbwtyp(R,Q),Cscsqtyp(R,Q),Dtypety
p(R,Q),Hpolar(R,Q)
1280   IF Q=1 AND Rdbtbtyp(R)=1 THEN ! IF RADAR HAS A BACK-TO-BACK ANTENNA,
1290     Q=2                         ! NEXT DATA LINE CONTAINS 2ND ANTENNA
1300     GOTO 1270                   ! PARAMETERS
1310   END IF
1320 Q=1
1330 NEXT R
```

```
1340 FOR I=1 TO Njm ! READ JAMMER PARAMETERS
1350      READ Jmbdw(I),Jmfrq(I),Jmerp(I)
1360 NEXT I
1370 FOR I=1 TO Nactyp  ! READ RADAR CROSS SECTION DATA
1380      J=0
1390 Nextrcs:!
1400      J=J+1
1410      READ Alpha(I,J),Rcs(I,J)
1420      IF (Alpha(I,J)<>9999) THEN  GOTO Nextrcs
1430      Ndeg(I)=J-1
1440 NEXT I
1450 !
1460 FOR A=1 TO Nac ! READ ACFT TYPE AND INITIAL POSIT AND VELOCITY
1470      READ Actype(A),Aclat(A),Aclong(A),Acalt(A),Achdg(A),Acvel(A)
1480 NEXT A
1490 FOR A=1 TO Nac ! READ AIRCRAFT FLIGHT PROFILE DATA
1500      Ship_flag(A)=0
1510      Follow(A)=0
1520      Cmmd(A)=1
1530      Tt=0
1540 Nexttime:!
1550      Tt=Tt+1
1560      READ Clock(A,Tt)
1570      IF Clock(A,Tt)<>9999 THEN
1580        READ Change(A,Tt),Acx(A,Tt),Acy(A,Tt)
1590        GOTO Nexttime
1600      END IF
1610 NEXT A
1620 Minscan=100
1630 !
```

```
1640 !  MATCHES GENERAL TYPE PARAMETERS TO EACH RADAR
1650 !
1660 FOR R=1 TO Nrd !  DETERMINES INITIAL ANTENNA POSIT
1670   Rdscn(R)=Rdscntyp(Rdtyp(R))
1680   Rdbtb(R)=Rdbtbtyp(Rdtyp(R))
1690   IF Rdbtb(R) THEN Rdant(R,2)=180
1700   Rmax(R)=Rmaxtyp(Rdtyp(R))
1710   Rdfrq(R)=Rdfrqtyp(Rdtyp(R))
1720   Rdfn(R)=Rdfntyp(Rdtyp(R))
1730   Rdnbw(R)=Rdnbwtyp(Rdtyp(R))
1740   Loss(R)=Losstyp(Rdtyp(R))
1750   Rvzero(R)=Rvzerotyp(Rdtyp(R))
1760   Q=1
1770   Rderp(R,Q)=Rderptyp(Rdtyp(R),Q)
1780   Rogan(R,Q)=Rogantyp(Rdtyp(R),Q)
1790   Rdazbw(R,Q)=Rdazbwtyp(Rdtyp(R),Q)
1800   Rdazsl(R,Q)=Rdazsltyp(Rdtyp(R),Q)
1810   Rdelbw(R,Q)=Rdelbwtyp(Rdtyp(R),Q)
1820   Cscsq(R,Q)=Cscsqtyp(Rdtyp(R),Q)
1830   Dtype(R,Q)=Dtypetyp(Rdtyp(R),Q)
1840   IF Q=1 AND Rdbtb(R)=1 THEN
1850     Q=2
1860     GOTO 1770
1870   END IF
1880   !
```

```
1880 !
1890 ! DETERMINE MIN ANTENNA SCANNING TIME OVER ALL RADARS
1900 IF Rdbtb(R)=! THEN
1910   Temp1=Rdscn(R)*.5
1920 ELSE
1930   Temp1=Rdscn(R)
1940 END IF
1950 Minscan=MIN(Minscan,Temp1)
1960 NEXT R
1970 IF Dt Minscan THEN Dt=Minscan ! SET TIME INCREMENT TO MIN SCAN TIME
1980                                ! IF LESS THAN INITIALLY DEFINED
1990 !
```

```
2000 !
2010 ! INITIALIZE RADAR AND JAMMER PROGRAM CONSTANTS
2020 !
2030 FOR R=1 TO Nrd
2040   IF Rdbtb(R) THEN
2050      Q=2
2060   ELSE
2070      Q=1
2080   END IF
2090   FOR Qq=1 TO Q
2100      Rdart(R)=SQR(Rdalt(R))
2110      Deg_scanned(R)=360.*Dt/Rdscn(R)
2120      Temp1=ABS(Rdgan(R,Qq))-ABS(Loss(R))
2130      Temp2=10.^(Temp1/10.)
2140      Temp3=(C^2)/(4*PI*Rdfrq(R)^2)
2150      Temp4=10.^(Rderp(R,Qq)/10)
2160      Rdreqn(R,Qq)=Temp2*Temp3*Temp4*2.9155E-7
2170      FOR J=1 TO Njm
2180           Jampwr(R,Qq,J)=(Jmerp(J)*Rdnbw(R)*Temp2*Temp3)/(Jmbdw(J)*2)
2190           Temp5=Jmbdw(J)*.5
2200           IF Qq=1 AND ABS(Rdfrq(R)-Jmfrq(J))<Temp5 THEN Nojam(R,J)=1
2210      NEXT J
2220   NEXT Qq
2230 NEXT R
2240 RETURN
2250 !
2260 !
```

```
2270 !  -=***OUTPUT CHOICE AND SETUP ROUTINE***=-
2280 Setup: !
2290       PRINTER IS CRT
2300       PRINT PAGE
2310       PRINT TABXY(5,5);Ds_name$;" DATASET LOAD COMPLETE"
2320       PRINT TABXY(5,7);"SELECT OUTPUT MODE"
2330       PRINT TABXY(10,9);"[1]  DATA"
2340       PRINT TABXY(10,10);"[2]  X-Y PLOT"
2350       PRINT TABXY(10,11);"[3]  PROB OF DETECTION PLOT"
2360       PRINT TABXY(10,12);"[4]  FIRST-DETECTION STATS"
2370       PRINT TABXY(5,13);"USE RETURN KEY"
2380 Setup1: !
2390       ENTER KBD;Output_choice
2400       IF Output_choice<>1 AND Output_choice<>2 AND Output_choice<>3 AND O
utput_choice<>4 THEN
2410         BEEP
2420         DISP
2430         GOTO Setup1
2440       END IF
2450       IF Output_choice=2 OR Output_choice=3 THEN
2460         PRINT TABXY(5,15);"FOR GRAPHICS, ENTER RADAR OF INTEREST  ";
2470 Setup2: !
2480         ENTER KBD;Rdr_choice
2490         IF Rdr_choice>Nrd THEN
2500           BEEP
2510           DISP
2520           GOTO Setup2
2530         END IF
2540         PRINT Rdr_choice
2550       END IF
```

```
2560        PRINT TABXY(5,18),"ENTER OUTPUT START TIME:   ";
2570        ENTER KBD;Output_start
2580        PRINT Output_start
2590        WAIT 1.5
2600        PRINT PAGE
2610        !
2620        ! PRINT OUTPUT HEADINGS
2630        !
2640        IF Output_choice=1 OR Output_choice=4 THEN
2650          ON KEY 0 LABEL "0) PRINT" GOTO Printit
2660          ON KEY 7 LABEL "7) CRT" GOTO Crtit
2670          WAIT
2680 Printit: !
2690        PRINTER IS 401
2700        Printno=401
2710        END IF
2720 Crtit: OFF KEY
2730        IF Output_choice=1 THEN
2740          PRINT "FASTE DATA OUTPUT";SPA(10);"DATASET:  ";Ds_name$
2750          OFF KBD
2760          PRINT
2770        END IF
2780        IF Output_choice=4 THEN
2790          PRINT "FASTE STATISTICS OUTPUT";TAB(39),"DATASET:  ",Ds_name$
2800          PRINT "START TIME:   ";Output_start
2810          DISP "WORKING"
2820        END IF
2830 RETURN
2840 !
```

```
2850 !
2860 !  -=***UPDATES AIRCRAFT POSITION, VELOCITY, AND JAMMER PARAMETERS***=-
2870 Updac: !
2880       A=0
2890 Updac1: ! UPDATE ACFT POSITS AND PASS DATA TO BUFFER ARRAY
2900       A=A+1
2910       Buffr(A,1)=T
2920       IF Acvel(A)=0 THEN
2930         IF A=Nac THEN RETURN
2940         GOTO Updac1
2950       END IF
2960           Temp=Dt*Acvel(A)/3600
2970           Temp1=Achdg(A)*Pid180
2980           Aclat(A)=Aclat(A)+Temp*COS(Temp1)
2990           Aclong(A)=Aclong(A)+Temp*SIN(Temp1)
3000           Buffr(A,2)=Aclat(A)
3010           Buffr(A,3)=Aclong(A)
3020           Buffr(A,4)=Acalt(A)
3030           Buffr(A,5)=Achdg(A)
3040           Buffr(A,6)=Acvel(A)
3050 Updac2: ! CHECK FLAG VARIABLES TO SEE IF ACFT IS IN A MANEUVER
3060       IF Accl(A) THEN  GOSUB Accell
3070       Buffr(A,6)=Acvel(A)
3080       IF Clmb(A) THEN  GOSUB Climb
3090       Buffr(A,4)=Acalt(A)
3100       IF Turn(A) THEN  GOSUB Turn
3110       Buffr(A,5)=Achdg(A)
3120       IF Hhom(A) THEN  GOSUB Home
3130       Tc=Cmmd(A)
```

```
3140    IF Clock(A,Tc) T THEN   ! TIME FOR NEXT MANEUVER?
3150      ON Change(A,Tc) GOSUB One,Two,Three,Four,Five,Six,Seven
3160      Cmmd(A)=Cmmd(A)+1 ! UPDATE COMMAND LINE POINTER
3170    END IF
3180    IF A>Nac THEN  GOTO Updac1
3190    FOR A=1 TO Nac
3200      IF Follow(A) THEN
3210        Aclat(A)=Aclat(Follow(A))
3220        Aclong(A)=Aclong(Follow(A))
3230        Acvel(A)=Acvel(Follow(A))
3240        Achdg(A)=Achdg(Follow(A))
3250        Acalt(A)=Acalt(Follow(A))
3260        Buffr(A,2)=Aclat(A)
3270        Buffr(A,3)=Aclong(A)
3280        Buffr(A,4)=Acalt(A)
3290        Buffr(A,5)=Achdg(A)
3300        Buffr(A,6)=Acvel(A)
3310      END IF
3320    NEXT A
3330   RETURN
3340 !
```

```
3350 One  ! TURN JAMMER ON
3360       Jamac(Acx(A,Tc),A)=1
3370 RETURN
3380 Two  ! TURN JAMMER OFF
3390       Jamac(Acx(A,Tc),A)=0
3400 RETURN
3410 Three  ! START ACCELERATION
3420       Accl(A)=1 ! FLAG ON
3430       Follow(A)=0
3440       Taccl(A)=ABS((Acy(A,Tc)-Acvel(A))/Acx(A,Tc)) ! ACCEL TIME
3450       Acaccl(A)=SGN(Acy(A,Tc)-Acvel(A))*ABS(Acx(A,Tc)) ! ACCEL RATE
3460 RETURN
3470 Four  ! START CLIMB
3480       Clmb(A)=1 ! FLAG ON
3490       Follow(A)=0
3500       Tclmb(A)=ABS((Acy(A,Tc)-Acalt(A))/Acx(A,Tc)) ! CLIMB TIME
3510       Acclmb(A)=SGN(Acy(A,Tc)-Acalt(A))*ABS(Acx(A,Tc)) ! CLIMB RATE
3520 RETURN
3530 Five ! START TURN
3540       Turn(A)=1 ! FLAG ON
3550       Hhom(A)=0 ! TERMINATE ANY ACTIVE HOMING MANEUVER
3560       Follow(A)=0
3570       Temp=Acy(A,Tc)-Achdg(A) ! DEGREES OF TURN
3580       Acturn(A)=Acx(A,Tc) ! TURN RATE
3590       IF (Temp 0) AND (Acturn(A) 0) THEN Temp=360-Temp
3600       IF (Temp 0) AND (Acturn(A) 0) THEN Temp=360+Temp
3610       IF (Temp 0) AND (Acturn(A) 0) THEN Temp=-Temp
3620       Tturn(A)=ABS(Temp/Acx(A,Tc)) ! TIME FOR TURN
3630 RETURN
```

```
3540 Si ! START HOMING
3650      Hhom(A)=1 ! FLAG ON
3660      Turn(A)=0 ! TERMINATE ANY ACTIVE TURN
3670      Follow(A)=0
3680      ! DEFINE HOMING TGT PARAMETERS
3690      Rdno=Acy(A,Tc)
3700      Hdlat(A)=Rdlat(Rdno)
3710      Hdlong(A)=Rdlong(Rdno)
3720      !
3730      Acturn(A)=Acx(A,Tc) ! TURN RATE
3740 RETURN
3750 Seven: !
3760      Follow(A)=Acx(A,Tc)
3770      Accl(A)=0
3780      Climb(A)=0
3790      Turn(A)=0
3800      Home(A)=0
3810 RETURN
3820 Accell !
3830      IF Taccl(A)>=Dt THEN
3840         Acvel(A)=Acvel(A)+Acaccl(A)*Dt ! UPDATE SPEED
3850         Taccl(A)=Taccl(A)-Dt ! UPDATE ACCEL TIME REMAINING
3860       ELSE
3870         Accl(A)=0 ! FLAG OFF
3880         Acvel(A)=Acvel(A)+Acaccl(A)*Taccl(A) ! UPDATE VELOCITY
3890      END IF
3900      IF Acvel(A)<10 THEN Acvel(A)=0 ! CLAMP SLOW MOVERS TO ZERO
3910 RETURN
```

```
3920 Climb !
3930       IF Tclmb(A)>Dt THEN
3940          Acalt(A)=Acalt(A)+Acclmb(A)*Dt ! UPDATE ALTITUDE
3950          Tclmb(A)=Tclmb(A)-Dt ! CLIMB TIME REMAINING
3960        ELSE
3970          Clmb(A)=0 ! FLAG OFF
3980          Acalt(A)=Acalt(A)+Acclmb(A)*Tclmb(A) ! UPDATE ALTITUDE
3990       END IF
4000 RETURN
4010 Turn !
4020       IF Tturn(A)>Dt THEN
4030          Achdg(A)=Achdg(A)+Acturn(A)*Dt ! UPDATE HEADING
4040          Tturn(A)=Tturn(A)-Dt ! TURN TIME REMAINING
4050        ELSE
4060          Turn(A)=0 ! FLAG OFF
4070          Achdg(A)=Achdg(A)+Acturn(A)*Tturn(A) ! UPDATE HEADING
4080       END IF
4090       IF Achdg(A)<0 THEN Achdg(A)=Achdg(A)+360
4100       IF Achdg(A)>=360 THEN Achdg(A)=Achdg(A)-360
4110 RETURN
```

```
4120 Home: !
4130      ! COMPUTE HEADING TO HOMING TGT
4140      Dlat=Hdlat(A)-Aclat(A)
4150      Dlong=Hdlong(A)-Aclong(A)
4160      IF SQR(Dlat^2+Dlong^2)<Acvel(A)*Dt/3600 THEN
4170        Acvel(A)=0
4180        RETURN
4190      END IF
4200      IF Dlat=0 AND Dlong>0 THEN Head=90
4210      IF Dlat=0 AND Dlong<=0 THEN Head=270
4220      IF Dlat<>0 THEN Head=ATN(ABS(Dlong/Dlat))*D180pi
4230      IF Dlat>0 AND Dlong<=0 THEN Head=360-Head
4240      IF Dlat<0 AND Dlong<=0 THEN Head=180+Head
4250      IF Dlat<0 AND Dlong>0 THEN Head=180-Head
4260      Temp=Achdg(A)-Head
4270      ! DEFINE TURN RATE I.E. DIRECTION OF TURN
4280      Acturn(A)=ABS(Acturn(A))
4290      IF Temp>0 AND Temp<180 THEN Acturn(A)=-Acturn(A)
4300      IF Temp<-180 THEN Acturn(A)=-Acturn(A)
4310      IF Temp>180 THEN Temp=360-Temp
4320      IF Temp<-180 THEN Temp=360+Temp
4330      Tturn(A)=ABS(Temp/Acturn(A)) ! TIME FOR TURN
4340      GOSUB Turn
4350 RETURN
4360 !
4370 !
```

```
4380 !
4390 !    -=***UPDATE RADAR ANTENNA POSITION, DETERMINE IF AIRCRAFT HAS***=-
4400 !    -=***  BEEN SCANNED, AND DETERMINE PROBABILITY OF DETECTION. ***=-
4410 Updrd !
4420       I=0
4430 Updrd1 !
4440       I=I+1
4450       IF I>Nrd OR I>Rdr_choice THEN RETURN
4460       IF Output_choice=2 OR Output_choice=3 THEN
4470          I=Rdr_choice
4480          Dt=Rdscn(I)
4490          IF Rdbrb(I) THEN Dt=Dt/2
4500          Deg_scanned(I)=360.*Dt/Rdscn(I)
4510       END IF
4520       A=0
4530 Updrd2 !
4540       !
4550       A=A+1
4560       IF A>Nac THEN  GOTO Updrd3
4570       Scanned(A,I)=0
4580       IF Acvel(A)=0 THEN  GOTO Updrd2
4590       Dx=Aclong(A)-Rdlong(I)
4600       IF Dx=0 THEN Dx=.0001
4610       Dy=Aclat(A)-Rdlat(I)
4620       IF Dy=0 THEN Dy=.0001
4630       Temp=Dx^2+Dy^2
4640       Dz=(Acalt(A)-Rdalt(I))/6076.1
4650       IF Dz=0 THEN Dz=.001
4660       Temp1=Dz^2
4670       Rr(A)=Temp+Temp1  ! SLANT RANGE SQUARED
4680       R(A)=SQR(Rr(A))   ! SLANT RANGE
```

```
4690      Dxy=SQR(Temp)
4700      Xx=Dx
4710      Yy=Dy
4720      GOSUB Atan2
4730      Phi(A)=Atng*D180pi
4740      IF Phi(A)<0 THEN Phi(A)=Phi(A)+360
4750      Q=1
4760      GOSUB Irep   ! RETURNS Aloss
4770      Irep_loss(A,1)=Aloss   ! ONE WAY TRANSMISSION LOSS
4780      IF Rdbtb(I) THEN
4790        Q=2
4800        GOSUB Irep
4810        Irep_loss(A,2)=Aloss
4820      END IF
4830      Q=1
4840      GOTO Updrd2
4850 Updrd3 !
4860      Cross=0
4870      Rdant(I,Q)=Rdant(I,Q)+Deg_scanned(I)  ! NEW ANTENNA POSIT
4880      IF Rdant(I,Q)>=360 THEN Cross=1
4890      IF Rdant(I,Q)>=360 THEN Rdant(I,Q)=Rdant(I,Q)-360
4900      Temp2=Rdant(I,Q)-Deg_scanned(I)  ! OLD ANTENNA POSIT
4910      !
```

```
4920      !***CHECK TARGETS FOR POSSIBLE DETECTION***
4930      !
4940      A=0
4950 Updrd4: !
4960      A=A+1
4970      IF A>Nac THEN
4980        IF Rdbtb(I) AND Q=1 THEN
4990          Q=2
5000          GOTO Updrd3
5010        ELSE
5020          GOTO Updrd1
5030        END IF
5040      END IF
5050      IF Acvel(A)=0 OR R(A)>Rmax(I) THEN  GOTO Updrd4
5060      IF Cross THEN  ! WAS THE AIRCRAFT SCANNED?
5070        IF Phi(A)>=Rdant(I,Q) AND Phi(A)<Temp2+360 THEN Updrd4
5080      ELSE
5090        IF Phi(A)>=Rdant(I,Q) OR Phi(A)<Temp2 THEN Updrd4
5100      END IF
5110      Scanned(A,I)=1
5120      !
5130      !***CALCULATE JAMMING POWER***
5140      ! SUMS PWR INTO RADAR FROM ALL APPLICABLE JAMMERS
5150      Tot_noise=1.38E-23*290*10^(Rdfn(I)/10)*Rdnbw(I)*1E6
5160      J=0
5170 Updrd5: !
5180      J=J+1
5190      IF J>Njm THEN  GOTO Updrd7
5200      IF Nojam(I,J) THEN  GOTO Updrd5
5210      I=0
```

```
5220 Updrd6 !
5230       L=L+1
5240       IF L>Nac THEN  GOTO Updrd5
5250       IF Jamac(J,L)=0 OR Acvel(L)=0 THEN  GOTO Updrd6
5260       Delphi=Phi(L)-Phi(A) ! ANGLE BETWEEN JAMMER AND TGT ACFT
5270       IF Delphi <=-180 THEN Delphi=Delphi+360
5280       IF Delphi>180 THEN Delphi=Delphi-360
5290       GOSUB Antpat ! RETURNS SDL: SIDELOBE LOSS DUE TO DELPHI
5300       Temp=-ABS(Sdl)-Irep_loss(L,Q)
5310       Templ=10.^(Temp/10.)
5320       Tot_noise=Tot_noise+(Jampwr(I,Q,J)*Templ) ! SUMS FOR TOTAL JAMMING P
WR
5330       GOTO Updrd6
5340 !
5350 !****CALCULATE RADAR CROSS SECTION****
5360 !
5370 Updrd7 !
5380       M=Actype(A)
5390       Aspect=180+Phi(A)-Achdg(A)
5400       IF Aspect>360 THEN Aspect=Aspect-360
5410       IF Aspect<0 THEN Aspect=Aspect+360
5420       GOSUB Trpolt
5430       Sigma=10.^(Sigdb/10)
5440 !
```

```
5450 !****CALCULATE PROBABILITY OF DETECTION****
5460 !
5470      Signal=10*LGT(Rdreqn(I,Q)*Sigma)-2*Irep_loss(A,Q)
5480      Tot_noise=10*LGT(Tot_noise)
5490      Se=Signal-Tot_noise-Rvzero(I) ! SIGNAL EXCESS
5500      IF Se -9 THEN Pd=0
5510      IF Se>9 THEN Pd=1
5520      IF Se>=-9 AND Se =9 THEN Pd=(1+SIN(Se*PI/18))/2
5530      Buffr(A,I+6)=Pd
5540      GOTO Updrd4
5550      !
5560 Outpt: !
5570    IF Output_start T THEN RETURN
5580    Nrdp6=Nrd+6
5590    SELECT Output_choice
5600    !
5610    CASE 1 ! DATA OUTPUT
5620      IF Nrd 4 THEN
5630        DISP "OUTPUT FORMAT CAN HANDLE ONLY 4 OR FEWER RADARS."
5640        WAIT 1.5
5650        GOTO Setup
5660      END IF
5670      ! HEADER AND FORMAT
5680      PRINT "ACFT  TIME     DX     DY    ALT  HEADG  SPEED ",
5690      FOR R=1 TO Nrd
5700        PRINT "RADAR";R,
5710        IF R=Nrd THEN PRINT
5720      NEXT R
```

```
5730      PRINT
5740      ! PRINTING ROUTINE
5750      FOR A=1 TO Nac
5760      IF Acvel(A)>0 THEN
5770      PRINT USING "3D#";A
5780           FOR J=1 TO 6
5790                PRINT USING "5D.D#";Buffr(A,J)
5800                Old_buffr(A,J)=Buffr(A,J)
5810           NEXT J
5820           FOR J=1 TO Nrd
5830             IF NOT Scanned(A,J) THEN
5840               PRINT "    *****";
5850             ELSE
5860                PRINT USING "3D.4D#";Buffr(A,J+6)
5870             END IF
5880           NEXT J
5890           PRINT
5900      END IF
5910      NEXT A
5920      PRINT
5930    !
5940    CASE 2 ! GRAPHICS OUTPUT
5950    IF Graphics_flag=1 THEN Picstart
5960      CINIT
5970 Riedges !
5980      Graphics_flag=1 ! FIRST TIME THRU ROUTINE
5990      PRINT PAGE
6000      PRINT TABXY(1,5);"INPUT SCREEN BORDERS" ! USER FORMAT INPUT
6010      PRINT "LEFT    ";
6020      ENTER KBD;Left_edge
6030      DISP
```

```
6040      PRINT Left_edge
6050      PRINT "RIGHT  ",
6060      ENTER KBD,Right_edge
6070      DISP
6080      PRINT Right_edge
6090      IF Right_edge =Left_edge THEN
6100        DISP "RIGHT EDGE LESS THEN LEFT EDGE.  TRY AGAIN."
6110        WAIT 2
6120        GOTO Rledges
6130      END IF
6140 Tbedges: !
6150      PRINT TABXY(1,8),"BOTTOM  ",
6160      ENTER KBD,Bottom_edge
6170      DISP
6180      PRINT Bottom_edge
6190      PRINT "TOP     ";
6200      ENTER KBD,Top_edge
6210      DISP
6220      PRINT Top_edge
6230      IF Top_edge =Bottom_edge THEN
6240        DISP "TOP EDGE IS LESS THAN BOTTOM EDGE.  TRY AGAIN"
6250        WAIT 2
6260        DISP
6270        PRINT TABXY(1,8),"                    "
6280        PRINT "                    "
6290        GOTO Tbedges
6300      END IF
6310      PRINT
6320      PRINT "DECLUTTER ?   Y OR N "
6330      ENTER KBD,Tics$
6340      PRINT PAGE
```

```
6350    PEN 2 ! RED
6360    Dw=Top_edge-Bottom_edge
6370    WINDOW 1.5*Left_edge,1.2*Right_edge,Bottom_edge-.1*Dw,Top_edge+.1*Dw
6380    CLIP Left_edge,Right_edge,Bottom_edge,Top_edge
6390    IF Tics$[1]="N" THEN
6400       LGRID 5,5
6410     ELSE
6420       LAXES 5,5,Left_edge,Bottom_edge,2,2,1
6430    END IF
6440    PEN 6 ! BLUE
6450    FOR R=1 TO Nrd ! LABEL RADAR LOCATIONS
6460      PLOT Rdlong(R),Rdlat(R),-2
6470      LABEL CHR$(8);"@"
6480    NEXT R
6490    PEN 2 ! RED
6500    PLOT Left_edge,Top_edge,-2 ! LABEL PLOT
6510    LABEL "DATASET  ";Ds_name$
6520    PLOT (Left_edge+Right_edge)/2,Top_edge,-2
6530    LABEL "RADAR OF INTEREST: ";Rdr_choice
6540    GRAPHICS ON
```

```
6550 Picstart !
6560      FOR A=1 TO Nac
6570        IF Acvel(A)<>0 THEN ! PLOT MOVING AIRCRAFT ONLY
6580          IF Skip_flag(A)=0 THEN Skip1
6590          IF Old_buffr(A,Rdr_choice+6)>=.5 THEN
6600            IF Buffr(A,Rdr_choice+6)>=.5 THEN
6610              LINE TYPE 1 ! SOLID LINE IF DET PROB >= .5
6620              PEN 1       ! COLOR WHITE
6630            END IF
6640          ELSE
6650            LINE TYPE 2 ! DOTTED
6660            PEN 5       ! BLUE
6670          END IF
6680          Jam_flag=0
6690          FOR J=1 TO Njm
6700            IF Jamac(J,A) AND NOT Nojam(Rdr_choice,J) THEN Jam_flag=1
6710          NEXT J
6720          IF Jam_flag THEN
6730            PEN 4 ! GREEN FOR AIRCRAFT WITH ACTIVE JAMMERS
6740          END IF
6750          PLOT Old_buffr(A,3),Old_buffr(A,2),-2 ! MOVE PEN TO LAST POSIT
6760          PLOT Buffr(A,3),Buffr(A,2),-1 ! DRAW LINE TO NEW POSIT
6770          IF Tics$[1]="N" THEN
6780           IF Buffr(A,1) MOD 60<Dt THEN ! PLOT 1 MINUTE TICS
6790            IF Buffr(A,3)>Left_edge AND Buffr(A,3)<Right_edge THEN
6800              IF Buffr(A,2)>Bottom_edge AND Buffr(A,2)<Top_edge THEN
6810                PLOT Buffr(A,3),Buffr(A,2),-2
6820                LINE TYPE 1
6830                LABEL  INT(Buffr(A,1)/60)
6840              END IF
6850            END IF
6860           END IF
6870          END IF
```

```
6880 Skip1: !
6890         Skip_flag(A)=1
6900         Old_buffr(A,2)=Buffr(A,2)
6910         Old_buffr(A,3)=Buffr(A,3)
6920         IF Buffr(A,Rdr_choice+6)<>PI THEN
6930           Old_buffr(A,Rdr_choice+6)=Buffr(A,Rdr_choice+6)
6940         END IF
6950       END IF
6960       NEXT A
6970       FOR R=1 TO Nrd ! RELABLES RADARS
6980         PEN 6 ! BLUE
6990         PLOT Rdlong(R),Rdlat(R),-2
7000         LABEL CHR$(8);"@"
7010       NEXT R
7020     !
7030     CASE 3 ! PROB DETECTION PLOT
7040     IF Graphics_flag THEN Plotstart
7050     GINIT
7060     Graphics_flag=1
7070     PEN 2
7080     WINDOW 1.1*Output_start-.1*Tfin,Tfin,-.25*Nac,Nac+2
7090     CLIP Output_start,Tfin,0,Nac+Gfac
7100     LAXES 10,1,Output_start,0,5,1
7110     LINE TYPE 3
7120     FOR A=1 TO Nac
7130       PLOT Output_start,A,-2
7140       PLOT Tfin,A,-1
7150     NEXT A
```

```
7160    LINE TYPE 1    ! SOLID
7170    PLOT Output_start,Nac+1,-2
7180    LABEL "DATASET:  ";Ds_name$
7190    PLOT (Output_start+Tfin)/2,Nac+1,-2
7200    LABEL "RADAR OF INTEREST:  ";Rdr_choice
7210    GRAPHICS ON
7220    PEN 1
7230 Plotstart: !
7240    FOR A=1 TO Nac
7250      IF Acvel(A)<>0 THEN      !PLOT ONLY MOVING TGTS
7260        IF Slip_flag(A) THEN
7270          PLOT Tlast,Old_buffr(A,Rdr_choice+6)*Gfac+A-Gfac/2,-2
7280          PLOT T,Buffr(A,Rdr_choice+5)*Gfac+A-Gfac/2,-1
7290        END IF
7300        Slip_flag(A)=1
7310        Old_buffr(A,Rdr_choice+5)=Buffr(A,Rdr_choice+6)
7320      END IF
7330    NEXT A
7340    Tlast=T
7350    !
```

```
7360    CASE 4  ! STATISTICS ROUTINE
7370    Tsim=50 ! NUMBER OF SIMULATIONS
7380    Rule=2  ! OPERATOR FACTOR DETECTION FACTOR
7390    FOR A=1 TO Nac
7400      FOR R=1 TO Nrd
7410        Nrdp6=R+6
7420        IF Scanned(A,R) THEN
7430          FOR S=1 TO Tsim
7440              IF Sim_rng(A,R,S) =0 THEN ! Sim_Rng IS COUNTING RADAR HITS
7450               ! USE OPERATOR EFFICIENCY = .7*(Pd) FOR 1st HIT
7460               IF Sim_rng(A,R,S)=0 THEN
7470                  Chance=0.7*Buffr(A,Nrdp6)
7480                ELSE
7490                  Chance=Buffr(A,Nrdp6)
7500                END IF
7510                 IF Chance =RND THEN   ! CONSECUTIVE RADAR HIT?
7520                  Sim_rng(A,R,S)=Sim_rng(A,R,S)-1   ! INCREMENT COUNTER
7530                 ELSE
7540                  Sim_rng(A,R,S)=0 ! RE-INITS  CONSECUTIVE HIT COUNTER
7550                 END IF
7560                 IF Sim_rng(A,R,S)=-Rule THEN !DETECTION RULE MET?
7570                  Temp=(Buffr(A,2)-Rdlat(R))^2+(Buffr(A,3)-Rdlong(R))^2
7580                  Sim_rng(A,R,S)=SQR(Temp) ! STORES DETECTION RANGE
7590                 END IF
7600              END IF
7610          NEXT S
7620        END IF
7630      NEXT R
7640    NEXT A
7650    END SELECT
7660 RETURN
7670 !
```

```
7680 !
7690 Output_stats: !
7700 FOR A=1 TO Nac
7710      DISP "SORTING"
7720      FOR R=1 TO Nrd  !  BUBBLE SORT OF SIMULATION DETECTION RANGES
7730        REPEAT
7740          Sorted=1
7750          FOR S=1 TO Tsim-1
7760            IF Sim_rng(A,R,S)>Sim_rng(A,R,S+1) THEN
7770              Sorted=0
7780              Dummy=Sim_rng(A,R,S)
7790              Sim_rng(A,R,S)=Sim_rng(A,R,S+1)
7800              Sim_rng(A,R,S+1)=Dummy
7810            END IF
7820          NEXT S
7830        UNTIL Sorted
7840      NEXT R
7850      !  COMPUTE STATISTICS
7860      PRINT
7870      PRINT
7880      PRINT "AIRCRAFT ";A,"DETECTION RANGE STATISTISTICS"
7890      PRINT "RADAR            MEAN   STD DEV   .25 QNT   .50 QNT   .75 QNT
PCT DET"
7900      FOR R=1 TO Nrd
7910        PRINT R,
7920        Start=1
```

```
7930 Stat1 !
7940         !DETERMINE INDEX FOR FIRST NON-ZERO DETECTION RANGE
7950         IF Start<=Tsim THEN
7960           IF Sim_rng(A,R,Start) =0 THEN
7970             Start=Start+1
7980             GOTO Stat1
7990           END IF
8000         END IF
8010         !
8020         IF Start=Tsim+1 THEN ! TARGET NOT DETECTED IN ANY OF SIMULATIONS
8030           PRINT "           NOT DET    NOT DET    NOT DET    NOT DET    NOT DET
     0"
8040         ELSE ! TARGET DETECTED AT LEAST ONE TIME
8050           Mean=Stdev=0
8060           !
8070           FOR S=Start TO Tsim
8080             Mean=Mean+Sim_rng(A,R,S)
8090           NEXT S
8100           Mean=Mean/(Tsim-Start+1)
8110           !
8120           FOR S=Start TO Tsim
8130             Stdev=Stdev+(Sim_rng(A,R,S)-Mean)^2
8140           NEXT S
8150           IF Tsim>Start THEN
8160             Stdev=SQR(Stdev/(Tsim-Start))
8170           ELSE
8180             Stdev=0
8190           END IF
8200           !
```

```
8210         ! DETERMINE QUANTILES
8220         Dummy=(Tsim-Start+1)/4
8230         IF Dummy MOD 1=0 THEN
8240           Qt25=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8250         ELSE
8260           Qt25=Sim_rng(A,R,Start+INT(Dummy))
8270         END IF
8280         Dummy=Dummy+Dummy
8290         IF Dummy MOD 1=0 THEN
8300           Qt50=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8310         ELSE
8320           Qt50=Sim_rng(A,R,Start+INT(Dummy))
8330         END IF
8340         Dummy=Dummy*3/2
8350         IF Dummy MOD 1=0 THEN
8360           Qt75=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8370         ELSE
8380           Qt75=Sim_rng(A,R,Start+INT(Dummy))
8390         END IF
8400         !
8410         Fctdet=(Tsim-Start+1)/Tsim
8420         !
8430         PRINT SPA(7);
8440         PRINT USING "6D.3D#";Mean;Stdev;Qt25;Qt50;Qt75;Fctdet
8450         PRINT " "
8460       END IF
8470     NEXT K
```

```
8480      IF A=Nac THEN Flip
8490      IF Printno>401 THEN
8500        DISP "DEPRESS CONT"
8510        PAUSE
8520        DISP
8530      END IF
8540 Flip: NEXT A
8550 RETURN
8560 !
8570 Trpolt:! USES ASPECT TO SOLVE RADAR X-SECTION BY INTERPOLATION
8580         ! OUTPUT  Sigdb
8590      IF Value Index(M,1) THEN  GOTO Trpolt2
8600      I1=1
8610      E1=Index(M,1)
8620      E2=0
8630 Trpolt1: !
8640      I1=I1+1
8650      IF I1 Ndeg(M) THEN  GOTO Trpolt3
8660      E2=Alpha(M,I1)
8670      IF Aspect =E2 THEN E1=E2
8680      IF Aspect =E2 THEN  GOTO Trpolt1
8690      Diff=Aspect-E1
8700      Sigdb=Rcs(M,I1-1)+Diff*(Rcs(M,I1)-Rcs(M,I1-1))/(E2-E1)
8710      RETURN
8720 Trpolt2: !
8730      Aspect=Aspect+360
8740 Trpolt3: !
8750      Diff=Aspect-Alpha(M,Ndeg(M))
8760      Sigdb=(Rcs(M,Ndeg(M))+Diff*(Rcs(M,1)-Rcs(M,Ndeg(M)))/(Alpha(M,1)+360
-Alpha(M,Ndeg(M)))
8770 RETURN
```

```
8780 !
8790 Antpat: ! RETURNS JAMMING ATTENUATION DUE TO AZIMUTH SEPARATION
8800       Limit=-40
8810       Zero=0.
8820       Xlob8=8.5
8830       Sdl=Pid2=PI/2.
8840       Jj=Dtype(I,Q)
8850       Conv=X3db(Jj)/(Rdazbw(I,Q)*0.5)
8860       Adel=ABS(Delphi*Conv)
8870       IF Adel=Zero THEN
8880         Sdl=Zero
8890         RETURN
8900       END IF
8910       IF Adel 30*Conv THEN
8920         Sdl=Farlob(Jj)
8930         RETURN
8940       END IF
8950       IF Jj=1 THEN
8960         IF Rdazbw(I,Q) =2 AND Adel Xlob8*PI THEN
8970           Sdl=Farlob(Jj)
8980           RETURN
8990         END IF
9000         Temp=(SIN(Adel)/Adel) 2
9010         IF Temp =1E-4 THEN
9020           Sdl=Limit
9030           RETURN
9040         END IF
9050         Templ=-10.*LGT(Pival(Jj)/Temp)
9060         IF Adel =Kzerol(Jj)*PI THEN
9070           Sdl=Templ
9080           RETURN
```

```
9090        END IF
9100        IF Adel>Xzero2(Jj)*PI THEN Templ=Templ-(Fstlob(Jj)-Rdazsl(I,Q))
9110        IF Adel>Xzero2(Jj)*PI THEN Templ=Templ-6
9120        IF Templ<Limit THEN Templ=Limit
9130      END IF
9140      IF Jj=2 THEN
9150        IF Adel>X2(Jj)*PI THEN
9160          Sdl=Seclob(Jj)
9170          RETURN
9180        END IF
9190        IF Adel<=X1(Jj)*PI THEN
9200          Temp=Coeff(Jj,1)*Adel^2+Coeff(Jj,2)*Adel+Coeff(Jj,3)
9210        ELSE
9220          IF ABS(Adel-Pid2)<=1E-5 THEN
9230            Temp=0.25
9240          ELSE
9250            Temp=(Pid2*COS(Adel)/(Pid2^2-Adel^2))^2
9260          END IF
9270        END IF
9280        IF Temp<4.053E-4 THEN
9290          Sdl=Seclob(Jj)
9300          RETURN
9310        END IF
9320        Templ=-10*LGT(Pival(Jj)/Temp)
9330      END IF
9340      Sdl=Templ
9350      RETURN
9360 !
9370 !
```

```
9380 Atan2 ! RETURNS ARC(RADIANS) OF ANGLE SUBTENDED BY Xx AT Yy
9390             IF Xx>0 AND Yy>0 THEN Atng=ATN(Xx/Yy)
9400             IF Xx<0 AND Yy<0 THEN Atng=PI+ATN(Xx/Yy)
9410             IF Xx<0 AND Yy>0 THEN Atng=2*PI+ATN(Xx/Yy)
9420             IF Xx>0 AND Yy<0 THEN Atng=PI+ATN(Xx/Yy)
9430             RETURN
9440 !
9450 !
9460 Irep ! RETURNS 1-WAY SIGNAL LOSS BETWEEN RADAR AND TARGET ACFT.
9470      ! ALGORITHMS AND SOURCE CODE DERRIVED FROM IREPS REV 2.2,
9480      ! LOSS SUBROUTINE (NOSC, SAN DIEGO, CA.)
9490 Antbwr=1.745E-2*Rdelbw(I,Q)
9500 Antelr=.01745
9510 Elmaxr=1.047
9520 IF NOT Cscsq(I,Q) THEN
9530   Antfac=1.39157/SIN(Antbwr/2)
9540   Patrfac=-(Elmaxr-Antelr)
9550  ELSE
9560   Elmaxr=Antelr+.78525
9570 END IF
9580 GOSUB Surface_init
9590 GOSUB Diffract_const
```

```
9600 IF Rkm<=Dmin THEN
9610   ! RANGE IS LESS THAN MINIMUM DIFFRACTION FIELD RANGE
9620   GOSUB Optical_limit
9630   IF Rkm>Opmax THEN
9640     Rng=Dmin
9650     GOSUB Diffraction
9660     ! INTERPOLATE BTWN OPMAX AND DMIN TO OBTAIN ALOSS
9670     Aloss=Oploss+(Oploss-Diff)*(Rkm-Opmax)/(Opmax-Dmin)
9680    ELSE
9690     IF Atheta<2*PI THEN
9700       ! RANGE IS LESS THAN OPMAX AND GREATER THAN OPEAK
9710       Thnext=2*PI
9720       GOSUB Plmda      ! RETURNS RANGE OF 1ST OPTICAL PEAK
9730       Opeak=Rnext
9740       Rng=Opeak
9750       IF Rkm>Opeak THEN
9760         GOSUB Oploss
9770         Plloss=Aloss
9780         ! INTERPOLATE TO OBTAIN LOSS BTWN OPMAX AND 1ST OPTICAL PEAK
9790         Aloss=Plloss-(Oploss-Plloss)*(Rkm-Opeak)/(Opeak-Opmax)
9800        ELSE
9810         ! LOSS IS IN THE ENVELOPE REGION (RKM < OPEAK)
9820         D=Rkm
9830         GOSUB Theta
9840         Rng=Rkm
9850         Atheta=Twopi
9860         GOSUB Oploss
9870        END IF
```

```
9880       ELSE
9890         !  LOSS IS IN THE ENVELOPE REGION (RKM,OPEAK)
9900         D=Rkm
9910         GOSUB Theta
9920         Rng=Rkm
9930         Atheta=Twopi
9940         GOSUB Op_loss
9950       END IF
9960     END IF
9970   ELSE
9980     !  LOSS IS SOLELY DIFFRACTION OR TROPOSCATTER
9990     Rng=Rkm
10000    GOSUB Diffraction
10010    Aloss=Diff
10020  END IF
10030  Aloss=Aloss-26.65-20*LGT(Rdfrq(I))   ! Remove Antenna Area
10040  RETURN
10050  !
10060  !
10070  Surface_init !  INITIALIZE CONSTANTS FOR IREP SUBROUTINES
10080  Ht=Rdalt(I)*.3048
10090  Hr=Acalt(A)*.3048
10100  Ht_duct=Ht_ductft*.3048
10110  Fsterm=32.45+8.686*LOG(Rdfrq(I))
10120  Arma=Rma(I)*1.852
10130  Rkm=R(A)*1.852
10140  Rnib=.*(Arma-.470)
10150  Ae=Ktac*6371
10160  Psilim=.01957/(Ktac*Rdfrq(I))^(1/3)
10170  Psi=Psilim
```

```
10180 Twopi=2*PI
10190 Halfpi=PI/2
10200 Pi4cwl=.04188*Rdfrq(I)  !  4*PI OVER WAVELENGTH
10210 Horizn=3.572*(SQR(Kfac*Ht)+SQR(Kfac*Hr))
10220 Dmin=Horizn+230.2*(Kfac*Kfac/Rdfrq(I))^(1/3)
10230 Hbfreq=.02094*Rdfrq(I)*5.1E-3*Wind*Wind
10240 Hfol=Hbfreq*.159155
10250 IF Rdfrq(I) 1500 THEN 10290
10260   Epsilon=80
10270   Sigma=4.3
10280   GOTO 10350
10290 IF Rdfrq(I) 3000 THEN 10330
10300   Epsilon=80-.00733*(Rdfrq(I)-1500)
10310   Sigma=4.3+.00148*(Rdfrq(I)-1500)
10320   GOTO 10350
10330 Epsilon=69-.00243*(Rdfrq(I)-3000)
10340 Sigma=6.52+.001314*(Rdfrq(I)-3000)
10350 Sigom=-Sigma*18000/Rdfrq(I)
10360 Delx=Armax/50
10370 Delx2=Delx/2
```

```
10380 Rmag=1
10390 Phi=PI
10400 Ref_flag=0
10410 RETURN
10420 !
10430 !
10440 Optical_limit: !  GEOMETRIC MODEL FOR HR 10K FT
10450 Altrap=0 ! DUCTING NOT USED IN OPTICAL REGION
10460 Dh=(Hr-Ht)*1E-3
10470 Ae2=Ae*2E-3
10480 Twoae=2*Ae
10490 Thefac=4.193E-5*Rdfrq(I)
10500 Vfac=(Ht+Hr)*Ae*1E-3
10510 Aetht=Ae*Ht*1E-3
10520 A1=SQR(Psi^2+2E-3*Ht/Ae)
10530 D1=D2=(A1-Psi)*Ae
10540 IF Hr Ht THEN D2=D2+(SQR(A1^2+2*Dh/Ae)-A1)*Ae
10550 D=D1+D2
10560 Htp=Ht-D1^2/Ae2
10570 Hrp=Hr-D2^2/Ae2
10580 Apd=Thefac*Htp*Hrp/D
10590 IF Hpolar(I,0)=0 THEN
10600   Sinpsi=SIN(Psi)
10610   GOSUB Ref
10620 END IF
10630 Atheta=Apd+Phi
10640 Aalpha=Dh/D-D/Twoae
10650 Rnow=D
10660 IF (Apd Halfpi) OR (Psi  Psilim) THEN C2
10670 C1: !  GRAZING ANGLE LIMIT
```

```
10680   Tnext=PI
10690   GOTO 10830
10700 C2 !  QUARTER WAVELENGTH LIMIT
10710   Tnext=3*Halfpi
10720   Rnow=.95*Horizn
10730   GOSUB Rlmda
10740   Rnow=Rnext
10750   IF Hpolar(I,0)=0 THEN
10760     Psi=Htp*1E-3/D1
10770     Sinpsi=SIN(Psi)
10780     GOSUB Ref
10790     Ref_flag=1
10800     Theta=Apd+Phi
10810   END IF
10820   GOTO C1
10830 Rng=Rsave=Rnow
10840 Opmax=Rng
10850 GOSUB Oploss
10860 Oploss=Aloss
10870 RETURN
10880 !
10890 !
10900 Oploss: !  OPTICAL REGION LOSS
10910 D=Rng
10920 IF Ref_flag THEN 10950
10930   Psi=Htp*1E-3/D1
10940   Sinpsi=SIN(Psi)
10950 Aalpha=Dn/D-D/Iwoae
10960 IF Aalpha<Elmax THEN RETURN
10970 Gamma=D1/Ae
```

```
10980 Beta=-(Gamma+Psi)
10990 GOSUB F_factor
11000 Losfac=Fsterm+8.686*LOG(Rng)
11010 IF Ffac =1E-7 THEN Aloss=Losfac+70
11020 IF Ffac>1E-7 THEN Aloss=Losfac-4.343*LOG(Ffac)
11030 E/loss=-8.686*LOG(Patd)
11040 RETURN
11050 !
11060 !
11070 Rlmda: !  SUBROUTINE TO FING RANGE WHERE A SPECIFIED VALUE OF THETA OCCURS
11080       !  RLMDA USES A FINITE DERIVATIVE IN A NEWTON ITERATION FOR THETA
11090       !  INPUTS   RNOW; D1; THNEXT; HTP, ATHETA
11100       !  OUTPUTS:  RNEXT
11110       !  SUBROUTINES USED:  THETA
11120       !  CONSTANTS   HORIZN
11130 Dsave=D1
11140 D=Rnow
11150 Dinc=MIN(.1,D*.01)
11160 FOR Icount=1 TO 10
11170   GOSUB Theta
11180   F=Atheta
11190   D=D+Dinc
11200   GOSUB Theta
11210   F1=Atheta
11220   Fp=(F1-F)/Dinc
11230   Dd=-(F-Thnext)/Fp
11240   IF Dd -D THEN 11270
11250    D=D/2
11260    GOTO 11320
```

```
11270   IF Horizn D+Dd THEN 11300
11280    D=(Horizn+D)/2
11290    GOTO 11320
11300   D=D+Dd
11310   IF (ABS(Dd) Dinc) AND (D Rnow) THEN 11330
11320 NEXT Icount
11330 Rnext=D
11340 RETURN
11350 !
11360 !
11370 Theta: !  SUBROUTINE FOR TOTAL PHASE DIFF, THETA, BTWN DIR AND REFL RAYS
11380        !  SOLVES A CUBIC EQN TO FIND REFLECTION POINT RANGE  D1
11390        !  INPUTS: D
11400        !  OUTPUTS:  ATHETA; D1; APD; HTP; PSI; SINPSI
11410        !  CONSTANTS: VFAC; AETHT; PHI; AE2; THEFAC
11420        !  SUBROUTINES USED: REF
11430 At=-1.5*D
11440 V=.5*D^2-Vfac
11450 W=Aetht*D
11460 FOR Index=1 TO 10
11470   D1sq=D1^2
11480   Fd1=D1*D1sq+At*D1sq+V*D1+W
11490   Fpd1=3*D1sq+2*D1*At+V
11500   Deld=Fd1/Fpd1
11510   D1=D1-Deld
11520   IF (D1 D) AND (D1 0) THEN 11550
11530     D1=D/2
11540     GOTO 11560
11550   IF ABS(Deld) .100 THEN 11570
11560 NEXT Index
```

```
11570 D2=D-D1
11580 Htp=Ht-D1*D1/Ae2
11590 Hrp=Hr-D2*D2/Ae2
11600 IF NOT Ref_flag THEN 11640
11610   Psi=Htp*1E-3/D1
11620   Sinpsi=SIN(Psi)
11630   GOSUB Ref
11640 Apd=Thefac*Htp*Hrp/D
11650 Atheta=Apd+Phi
11660 RETURN
11670 !
11680 !
11690 Diffract_const: !  DIFFRACTION/TROPOSCATTER REGION CONSTRAINTS
11700 Freq=Rdfrq(I)
11710 IF Ht_duct=0 THEN Evap_duct
11720 !  CONSTANTS FOR GROUND-BASED DUCT
11730   Atten=0
11740   Tlrfac=2
11750   T1=Hr/Ht_duct
11760   IF (Freq<=150) AND (T1<.8) THEN Fz=-60*(T1-.5)^2
11770   IF (Freq<=150) AND (T1>=.8) THEN Fz=1.14*T1^(-6.26)-10
11780   IF (Freq>150) AND (T1<1) THEN Fz=10-200*(T1-.5)^4
11790   IF (Freq>150) AND (Freq<=350) AND (T1>=1) THEN Fz=7.5*T1^(-13.3)-10
11800   IF (Freq>350) AND (T1>=1) THEN Fz=12.5*T1^(-8)-15
11810   Difac=Fsterm-Fz+E_loss
11820   GOTO Tropo
```

```
11830 Evap_duct: !  STANDARD DIFF. CONSTANTS
11840   Tlrfac=1
11850   Rfac=4.705E-2*Freq^(1/3)
11860   Zfac=2.214E-3*Freq^(2/3)
11870   Hmin=1/Zfac
11880   Zt=MAX(Hmin,Ht*Zfac)
11890   Zr=MAX(Hmin,Hr*Zfac)
11900   C1=-14.8
11910   C2=.49
11920   C3=-36.9
11930   C4=-.1
11940   C5=102
11950   Fzt=C1*(Zt/4.72)^C2+C3*(Zt/4.72)^C4+C5
11960   Fzr=C1*(Zr/4.72)^C2+C3*(Zr/4.72)^C4+C5
11970   Atten=1.973*Rfac
11980   Tlm=216.7
11990   Difac=51.1+Tlm-Fzt-Fzr+4.343*LOG(Rfac)
12000 Tropo: !
12010   Tfac=.08984/Kfac
12020   Trofac=13.029*LOG(Freq)+49.9-Tfac*Horizn+Exloss
12030 RETURN
12040 !
12050 !
12060 Diffraction: !  RETURNS LOSS IN DIFFRACTION/TROPOSCATTER REGION @ RNG
12070 !   INPUTS  RNG
12080 !   OUTPUTS   DIFF
12090 !   CONSTANTS:  TFAC, TROFAC; DIFAC; ATTEN, TLRFAC
12100 Tlr=4.343*LOG(Rng)
12110 Tloss=Tfac*Rng+2*Tlr+Trofac
12120   Diff=Difac+Tlr*Tlrfac+Atten*Rng
12130   Dif=Diff-Tloss
```

```
12140   IF Dif -18 THEN RETURN
12150   IF Dif 18 THEN
12160     Diff=Diff-4.343*LOG(1+EXP(Dif/4.343))
12170   ELSE
12180     Diff=Tloss
12190   END IF
12200   RETURN
12210 RETURN
12220 !
12230 !
12240 Aantpat: !   *** ANTENNA PATTERN FUNCTION SUBROUTINE ***
12250 ! INPUTS:  ELEVATION ANGLE FOR WHICH ANTENNA PATTERN DISIRED: ANGLE
12260 ! OUTPUTS  NORMALIZED ANTENNA PATTERN FACTOR:  PATFAC
12270 ! CONSTANTS  ANTELR, ANTFAC, ANTBWR, PATRFAC;
12280 Patfac=1
12290 Apat=Angle-Antelr
12300 IF Cscsq(I,0) THEN 12380
12310   IF ABS(Apat) 1E-6 THEN RETURN
12320   IF Angle Antelr+Patrfac THEN 12350
12330   Patfac=0.03
12340   RETURN
12350 Ufac=Antfac*SIN(Apat)
12360 Patfac=ABS(SIN(Ufac)/Ufac)
12370 RETURN
12380 Patfac=MIN(1,MAX(.03,1+Apat/Antbwr))
12390 IF Apat Antbwr THEN Patfac=Antbwr/SIN(ABS(Apat))
12400 RETURN
12410 !
```

```
12420 !
12430 Ruf: ! RETURNS SURFACE ROUGHNESS COEFFICIENT FOR SPECIFIED GRAZING ANGLE
12440 !   INPUT.  SURFACE ROUGHNESS IS FUNCTION OF WIND SPEED.
12450 !   INPUTS:  GRAZING ANGLE:  PSI; SIN(PSI)
12460 !   OUTPUTS: NORMALIZED MAGNITUDE OF REFLECTTED SIGNAL:  RUF
12470 !   CONSTANTS: HBFREQ; HFOL
12480 Eterm=-2*(Hbfreq*Sinpsi)^2
12490 IF Eterm<-.95555 THEN 12520
12500   Ruf=EXP(Eterm)
12510   RETURN
12520 Hfpsi=Hfol*Psi
12530 IF Hfpsi>.26 THEN Ruf=.15
12540 IF Hfpsi<=.15 THEN Ruf=.5018913-SQR(.2090248-(Hfpsi-.55189)^2)
12550 RETURN
12560 !
12570 !
12580 Ref: ! REFLECTION COEFFICIENT
12590 Rr=Epsilon-COS(Psi)^2
12600 Ar=(Rr*Rr+Sigom*Sigom)^.25
12610 Th=ATN(Sigom/Rr)/2
12620 Rx=R*COS(Th)
12630 Ry=R*SIN(Th)
12640 Aa=Epsilon*Sinpsi-Rx
12650 Ab=Sigom*Sinpsi-Ry
12660 Ac=Epsilon*Sinpsi+Rx
12670 Adx=Sigom*Sinpsi+Ry
12680 Rx=(Aa*Ac+Ab*Adx)/(Ac*Ac+Adx*Adx)
12690 Ry=(Ab*Ac-Aa*Adx)/(Ac*Ac+Adx*Adx)
12700 Rmag=SQR(Rx*Rx+Ry*Ry)
```

```
12710 IF Rx<>0 THEN
12720   Phi=ATN(Ry/Rx)
12730   IF Rx<0 THEN Phi=Phi+PI
12740 ELSE
12750   IF Ry<0 THEN Phi=-Halfpi
12760   IF Ry>0 THEN Phi=Halfpi
12770   IF Ry=0 THEN Phi=0
12780 END IF
12790 Phi=-Phi
12800 IF Phi<0 THEN Phi=Phi+Twopi
12810 IF NOT Hpolar(I,Q) THEN RETURN
12820 Rx=SQR(1+Rmag*Rmag+2*Rmag*COS(PI-Phi))
12830 Aa=ASN(Rmag*SIN(Phi+PI)/Rx)
12840 Phi=PI-Aa
12850 Rmag=Rx/2
12860 Phi=-Phi
12870 IF Phi<0 THEN Phi=Phi+Twopi
12880 RETURN
12890 !
12900 !
12910 F_factor !  RETURN VALUE OF PATTERN PROPAGATION FACTOR   F
12920 !   INPUTS   ANGLES  PSI; AALPHA; BETA, GAMMA, HR; RMAG,
12930 !            ATHETA, PATFAC
12940 !  OUTPUTS: FFAC
12950 !  SUBROUTINES CALLED   AANTPAT, RUF
12960 Angle=Aalpha
12970 GOSUB Aantpat
12980 Patd=Pattac
12990 Angle=Beta
13000 GOSUB Aantpat
13010 GOSUB Ruf
```

```
13020 Divfac=1/SQR(1+2*Gamma/Sinpsi)
13030 Dr=Divfac*Patfac*Rmag*Ruf
13040 Ffac=Patd^2+Dr^2+2*Dr*Patd*COS(Atheta)
13050 RETURN
13060 !
13070 Exit: !
13080 SELECT Output_choice
13090 CASE 1 !   DATA
13100 CASE 2 !   X-Y PLOT
13110       ON KEY 0 LABEL "0) DUMP " GOTO Dumpit
13120 CASE 3 !   PD PLOT
13130       ON KEY 0 LABEL "0) DUMP " GOTO Dumpit
13140 CASE 4 !   STATS
13150       GOSUB Output_stats
13160 END SELECT
13170 ON KEY 7 LABEL "  7) EXIT" GOTO Endit
13180 WAIT
13190 !
13200 Dumpit: !
13210       DUMP GRAPHICS  TO 401
13220       PRINTER IS CRT
13230       GOTO Exit
13240 Endit: !
13250 GRAPHICS OFF
13260 PRINT PAGE
13270 PRINTER IS CRT
13280 DISP "CLEARING DATA FILE"
13290 LOAD "FASTS",Final
13300 Final: DISP "BYE"
13310 END
13340 Dat: !  DATASET NAME
```

APPENDIX B. FASTS DATA INPUT GUIDE

A. FILE STRUCTURE

The FASTS data file is compsed of a series of BASIC language DATA statements with interspersed lines of comment to aid in file building and readability. When the program is executed, the user is prompted to enter the name of the data file containing the simulation run parameters. The file is then physically attached to the end of the source code and becomes a part of the FASTS program. Statements or commands in subroutine IREP read the parameters from the DATA statements and assign them to the program variables.

Each line containing data begins with the key word DATA. Numerical quantities may be in decimal or integer format and must be separated by commas. Ommission of a comma is the most common mistake made in building a data file.

Data elements are read sequentially; hence no parameters may be ommitted.

Since the exclamation point, and all information to its right, are ignored during execution, it is used to provide lines for spacing, parameter list headings, and user comments needed to make the file more easily interpreted.

The data file has eight major sections: IREPS; Size; Radar Site; Radar Parameters; Jammer Parameters; Aircraft Initialization; and Aircraft Flight Profile.

1. IREPS

This section contains parameters defining atmospheric conditions.

Parameter Definitions:

K	Equivalent earth radius (dimensionless)
DUTC HT	Altitude of the top of the first trapping layer above the earth's surface (ft)
WIND	Wind speed (knots)

Data Source:

For the standard day, K=1.33 and DUCT HT=0 are used. Parameters for actual conditions may be determined from the IREPS system output. To determine K, run the IREPS program with data for current or predicted atmospheric conditions selecting the Radar Loss Display option. On completion, enter K and depress the ENTER key; the value for K will be displayed. Duct height may be read directly from the IREPS Propagation Conditions Summary display.

2. Size

This section contains time parameters and specifies the number of data elements present in the data file for radars, jammers, and aircraft.

Parameter Definitions:

NAC	Total number of aircraft in the simulation (15 max)
NJM	Total number of jammers types in simulation (15 max)
NRD	Total number of radars in the simulation (15 max)
NACTYP	Total number of aircraft types defined (15 max)

NRDTYP	Total number of radar types defined (15 max)
DT	Simulation time increment--upper bound (sec)
TFIN	Simulation end time (sec)

3. Radar Site

This section contains parameters specifying the type and location of each radar.

Parameter Definitions:

RDTYP	Type specification for the radar
RDLAT	Y-axis radar location coordinate (nm)
RDLONG	X-axis radar location coordinate (nm)
RDALT	Radar antenna altitude (ft)

4. Radar Parameters

This section contains parameters for each of the different types of radar systems. Note that parameters for as many as fifteen different types of radar systems may be entered as a data base even though each is not actually used in the simulation.

Parameter Definitions:

RDSCNTYP	Radar antenna scan time (sec)
RDBTBTYP	Antenna design (1 = Back-to-Back; 0 = Single)
RMAXTYP	Radar maximum range (nm)
RVZEROTYP	Detection visibility threshold (dB)
RDERPTYP	Radar effective radiated power (dB)
RDFRQTYP	Radar frequency (MHz)
RDGANTYP	Radar receiving antenna gain (dB)
RDFNTYP	Radar receiver noise figure (dB)

RDNBWTYP	Radar noise bandwidth (MHz)
LOSSTYP	Radar receiver loss (dB)
RDAZBWTYP	Radar antenna pattern azimuth beamwidth (deg)
RDAZSLTYP	Antenna pattern gain in the first side lobe (dB)
RDELBWTYP	Radar antenna pattern elevation beamwidth (deg)
CSCSQTYP	Vertical antenna pattern (1 = csc^2; 2 = sin x/x)
DTYPETYP	Horizontal antenna pattern (1 = Type 1; 2 = Type 2)
HPOLAR	Radar beam polarization (1 = horizontal; 2 = vertical)

Data Source:

Parameter data for most threat radar systems is found in:

Defense Intelligence Agency, Radar Handbook--Eurasian Communist Countries, DST-1710H-507-80-Vol. 3, December 1980

Effective radiated power may be computed as the product of the transmitter power times the gain of the antenna.

Data may be converted to decibel (dB) notation by the use of the following relationship:

dB = 10 log (X) where X is the parameter to be converted.

5. Jammer Parameters

This section contains radar jammer parameters listed for each jammer type.

Parameter Definitions:

JMBW	Jammer bandwidth (MHz)
JMFRQ	Jammer frequency (MHz)
JMERP	Jammer effective radiated power

Data Source:

Data for jammer parameters may be found in:

Commander, Operational Test and Evaluation Squadron FIVE, <u>EA-6B Tactical Employment Guide</u>, OTG 533-01-80 series

6. <u>Aircraft Parameters</u>

This section contains radar cross section data listed for each aircraft type. Up to 360 entries of aspect angle and associated radar cross section may be entered for each aircraft. Note that data for as many as fifteen aircraft may be contained in the parameter file as a data base even if each is not used in the simulation.

Parameter Definitions:

ALPHA Aircraft aspect angle (deg)

RCS Radar cross section gain for ALPHA (dB)

Data Source:

Radar cross section data for aircraft may be found in the tactical manual or supplemental NATOPS manual for each aircraft.

7. <u>Aircraft Initialization</u>

This section contains parameters specifying the type and initial position and velocity for each aircraft in the simulation.

Parameter Definitions:

ACTYP Type specification for the aircraft

ACLAT Y-axis coordinate, aircraft initial position (nm)

ACLONG X-axis coordinate, aircraft initial position (nm)

ACALT	Aircraft initial altitude (ft)
ACHDG	Aircraft initial heading (deg)
ACVEL	Aircraft initial speed (knots)

8. Aircraft Flight Profile

This file contains a subfile for each aircraft. Lines within each subfile contain up to fifteen commands for that aircraft and are listed in order of the command initiation time.

Parameter Definitions:

TIME — Command initiation time (sec)
A 9999 entry indicates the end of the an aircraft's profile command list.

CHANGE — Command type
1 = Jam ON
2 = Jam OFF
3 = Accelerate (decelerate)
4 = Climb (Descend)
5 = Turn
6 = Home
7 = Follow

X — Command parameter

Jam ON/Jam OFF	Jammer type number
Accelerate	Rate (knots/sec)
Climb	Rate (feet/sec)
Turn	Rate (deg/sec)
Home	Rate (deg/sec)
Follow	Aircraft to be followed

Note: The parameters for accelerate, climb, and turn are signed quantities with negative values indicating decelerate, descend, and turn left.

Y — Command target parameter

Jam ON/Jam OFF	Must be 0
Accelerate	New speed (knots)
Climb	New altitude (feet)
Turn	New heading (deg)
Home	Radar site number
Follow	Must be 0

B. DATA FOR DUAL ANTENNA RADARS

Radar systems having two antennas mounted in back-to-back fashion can be simulated by FASTS.

If the variable RDBTB is read as 1 for a radar system, the program will seek data parameters for the second antenna system. These parameters are listed in the data file line directly following the line containing the data for the first system. Data for the following parameters must be entered: RDERPTYP, RDGANTYP, RDAZBWTYP, RDAZSLTYP, RDELBWTYP, CSCSQTYP, DTYPETYP, and HPOLAR.

C. SAMPLE DATA FILE

The following is a sample data file containing multiple radars, radar types, aircraft, and aircraft types:

```
10 Dat:!   DATASET NAME
20 DATA    WAS1
30 !
40 !IREPS     K        DUCT HT (FT)      WIND
50 DATA       1.33,      0,                8
60 !
70 !     NAC  NJM  NRD   NACTYP  NRDTYP    DT    TFIN
80 DATA  7,    2,   2,     2,       2,      10,  1000
90 !
100 Rdrdat:!
110 !          RDTYP    RDLAT    RDLONG    RDALT
120 DATA        1,        0,       0,        80      ! RDR 1
130 DATA        2,        0,       5,        80      ! RDR 2
140 !
150 !     RDSCNTYP    RDBTBTYP  RMAXTYP   RVZEROTYP
160 DATA    5,          0,        250,        0      ! RDR 1
170 DATA    5,          1,        125,        0      ! RDR 2
180 !
190 !
200 !     RDERPTYP   RDFRQTYP  RDGANTYP  RDFNTYP  RDNBWTYP  LOSSTYP
210 DATA   90,        1000,      40,       10,       .5,       10    ! RDR 1
220 DATA  102,         850,      35,        7,      0.1,        7    ! RDR 2
230 DATA   98,                   31
240 !
250 !
260 !     RDAZBWTYP  RDAZSLTYP  RDELBWTYP  CSCSQTYP  DTYPETYP    HPOLAR
270 DATA    4,         -20,         4,         0,        1,         1  ! RDR 1
280 DATA    3,         -20,         7,         0,        1,         1  ! RDR 2
290 DATA   3.5,        -20,         4,         1,        1,         0
300 !
```

```
310 Jmdat:!
320 !        JMBW   JMFRQ     JMERP
330 DATA   100,     1000,      800
340 DATA   150,      900,    14000
350 !
360 !
370 !      ALPHA     RCS
380 DATA     0,      14
390 DATA   180,      14
400 DATA   9999,     00.0
410 !
420 DATA     0,      -3
430 DATA   180,      -3
440 DATA 9999,        0
450 !
460 Acdat:!
470 !         ACTYPE   ACLAT   ACLONG   ACALT   ACHDG   ACVEL
480 DATA        1,      100,      0,    5000,    180,   360  ! JAMMER
490 DATA        1,      100,      0,    5000,    180,   360  ! SHOOTER(R)
500 DATA        1,      100,      0,    5000,    180,   360  ! SHOOTER(L)
510 DATA        1,      100,      0,    5000,    180,   360  ! SHOOTER(C)
520 DATA        2,      100,      0,    5000,    180,   360  ! MISSILE(R)
530 DATA        2,      100,      0,    5000,    180,   360  ! MISSILE(L)
540 DATA        2,      100,      0,    5000,    180,   360  ! MISSILE(C)
550 !
```

```
560 !       TIME   CHANGE      X        Y
570 !ACFT1
580 DATA    1,       6,        3,       1
590 DATA  250,       4,     -100,    1000  ! DECEND TO 1000 FT
600 DATA  500,       3,       -5,     300  ! DECELL TO 300 KTS
610 DATA  500,       1,        1,       0  ! JAMMER 1 ON
620 DATA  500,       1,        2,       0  ! JAMMER 2 ON
630 DATA  740,       5,       -3,     181  ! TURN
640 DATA  860,       5,        3,     180  ! TURN
650 DATA  980,       5,        3,     045  ! TURN
660 DATA   9999
670 !
680 !ACFT2
690 DATA    1,       7,        1,       0  ! FOLLOW JAMMER
700 DATA  500,       3,        5,     420  ! ACCEL TO 420
710 DATA  500,       5,        3,     230  ! TURN
720 DATA  655,       6,        3,       1  ! HOME TO 1
730 DATA  740,       5,       -3,     360  ! TURN AFTER SHOT
740 DATA 9999
750 !
760 !ACFT3
770 DATA    1,       7,        1,       0  ! FOLLOW JAMMER
780 DATA  500,       3,        5,     420  ! ACCEL TO 420
790 DATA  500,       5,       -3,     130  ! TURN
800 DATA  680,       6,        3,       2  ! HOME TO 2
810 DATA  750,       5,       -3,     360  ! TURN AFTER SHOT
820 DATA 9999
830 !
```

```
840 !ACFT4
850 DATA    1,      7,       1,       0  ! FOLLOW JAMMER
860 DATA  500,      3,       5,     360  ! MAINTAIN 360 KTS
870 DATA  700,      5,      -3,     360  ! TURN AFTER SHOT
880 DATA 9999
890 !
900 !ACFT5
910 DATA    1,      7,       2,       0  ! FOLLOW SHOOTER(R)
920 DATA  730,      6,       3,       1  ! HOME TO RDR 1
930 DATA  730,      3,      50,     550  ! ACCEL
940 DATA  730,      4,    -100,      50  ! FALL  TO 50 FT
950 DATA 9999
960 !
970 !ACFT6
980 DATA    1,      7,       3,       0  ! FOLLOW SHOOTER(L)
990 DATA  740,      6,       3,       2  ! HOME TO RDR 2
1000 DATA  740,      3,      50,     550  ! ACCEL
1010 DATA  740,      4,    -100,      50  ! FALL  TO 50 FT
1020 DATA 9999
1030 !
1040 !ACFT7
1050 DATA    1,      7,       4,       0  ! FOLLOW SHOOTER(C)
1060 DATA  700,      6,       3,       1  ! HOME TO RDR 1
1070 DATA  700,      3,      50,     750  ! ACCEL
1080 DATA  700,      4,    1000,   10000  ! CLIMB TO 10000 FT
1090 DATA 9999
```

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